TIGHT BINDING

SUBSURFACE EXPLORATION AND SAMPLING OF SOILS FOR CIVIL ENGINEERING PURPOSES

AMERICAN SOCIETY OF CIVIL ENGINEERS FOUNDED 1852

REPORT ON A RESEARCH PROJECT OF THE

COMMITTEE ON SAMPLING AND TESTING
SOIL MECHANICS AND FOUNDATIONS DIVISION
AMERICAN SOCIETY OF CIVIL ENGINEERS

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PREFACE

The following report presents the results of the first major research project organized by the Soil Mechanics and Foundations Division of the American Society of Civil Engineers and is issued under the sponsorship of the Engineering Foundation, Harvard University, and the Waterways Experiment Station. This final report is the result of the personal efforts of M. Juul Hvorslev, who served the project first as research engineer and later as member of the Committee on Sampling and Testing. The report was completed by Dr. Hvorslev late in 1947 and printed in preliminary form early in 1949. Before final printing, an appendix covering recent developments, a name index, and a subject index were added to the report.

In scope this report is an authoritative reference work on subsurface exploration and sampling of soil and rock. Its value to the practicing engineer is that it includes under one cover

(1) Information and general data on all methods of subsurface exploration and sampling, with a complete bibliography for detailed information on specific topics.

(2) A clear and logical delineation of factors influencing the quality of samples, and rules covering the design and operation of equipment for obtaining undisturbed samples.

Neither the report nor experienced foundation engineers on the committees advocate requiring undisturbed samples for all soil investigations. Many projects are adequately served by the relatively inexpensive exploratory procedures summarized in the report under the heading "Reconnaissance and General Exploration." More elaborate explorations are warranted only when the character of the project and the results of preliminary explorations indicate that a complete investigation and laboratory tests are required to insure an adequate foundation design.

The committees wish to emphasize that when undisturbed samples and major laboratory tests are required, only the best possible sampling procedures are justified. It is essential that undisturbed sampling operations be performed under field supervision of a competent soils engineer. Necessary variations in sampling methods for different soil types, changes in procedure to improve results as sampling progresses, and the many measurements and records required to insure an adequate return from the operation -- all of which are described in the report -- require a thorough knowledge of soil mechanics for their understanding and proper execution.

The report has been reviewed by all who have been members of the sponsoring committees during the entire period of the research and is enthusiastically endorsed by all reviewers. The report is presented to the engineering profession with the conviction that it constitutes a significant contribution to soils and foundation engineering practice.

The Committee on Sampling and Testing
and
The Executive Committee
Soil Mechanics and Foundations Division
American Society of Civil Engineers

November 1949

FOREWORD

HISTORICAL SUMMARY

The Committee on Sampling and Testing, with Mr. Joel D. Justin as Chairman, was organized in 1937 by the Soil Mechanics and Foundations Division of the American Society of Civil Engineers. The first project undertaken by the committee was a study of exploration and sampling of subsurface materials with the primary purpose of developing better methods for obtaining undisturbed samples of soils. Arrangements were made to obtain the cooperation of other organizations and institutions in this project, and it was decided to engage a research engineer to carry out the work under general direction of the committee The writer was engaged in this capacity on February 1, 1938 This plan was made possible by the financial assistance of The Engineering Foundation and the offer of the Graduate School of Engineering, Harvard University, to provide office and laboratory facilities for the research engineer.

The first part of the research consisted of a fact finding survey, embracing an analysis of the problems encountered and a critical review of the methods and equipment currently used in sampling of soils The results of the survey were presented in a report, entitled "The Present Status of the Art of Obtaining Undisturbed Samples of Soils", which was printed in 1000 copies in March 1940 and reprinted in 1200 copies as an appendix to the Proceedings of the Conference on Soil Mechanics and Its Applications, Purdue University, July 1940.

The experimental part of the research was advanced concurrently with the fact finding survey. Methods and equipment were developed for determining the extent and causes of disturbance in soil samples. Preliminary experiments were made during practical sampling operations, but systematic tests in uniform soil deposits were required to segregate and determine the influence of the many factors which govern the disturbance of soil samples and the success of the sampling operation. Uniformly stratified soil deposits, suitable for such experiments, were found near Hartford, Connecticut, and Woods Hole, Massachusetts, and several series of experiments were performed in these localities between May 1939 and February 1941.

In conjunction with these experiments, the Missouri River Division, Corps of Engineers, performed a series of comparative tests with large samplers at Marshall Creek Dam. These tests were started in December 1938, the field work was completed in April 1939 and the laboratory investigation of the samples in September 1939. A report on the results of the experiments was issued by the

Missouri River Division in October 1940, see (112) in the classified bibliography. In these experiments the Committee on Sampling and Testing was represented by its research engineer, who acted as consultant and participated in the writing of the report.

The results of all the above mentioned experiments were applied in practical sampling operations near Boston. New problems appeared, and it became evident that a large additional series of systematic tests in very uniform soil was needed to obtain more detailed data. Special sampling, recording, and testing equipment was designed and built during the fall of 1941, and detailed plans were prepared for experiments to be performed in the spring of 1942. However, the experiments required the cooperation of several organizations and had to be abandoned because of the priority of other activities in connection with the war effort. Likewise, time and circumstances made it impossible to perform a planned and badly needed series of experiments on the use of core boring methods in sampling of soils. The special equipment was, however, used in experiments made in conjunction with practical sampling operations. Such experiments as well as laboratory tests on various methods of preserving and handling samples and on the extent and degree of disturbance in samples were continued until completion of this report. A large amount of new data was obtained, but a detailed analysis was often difficult since the number of variables entering each experiment could not always be controlled under practical working conditions. It is therefore to be regretted that the planned and final series of experiments in uniform soil deposits could not be carried out.

Independent sampling experiments were performed by the Providence District and the Waterways Experiment Station, Corps of Engineers, and recently by the Special Engineering Division, The Panama Canal. The writer acted as consultant on some of these experiments, and the results were made available to the committee.

In addition to the published report on the results of the fact finding survey, four progress reports or papers on special phases of the research were prepared and presented at the following meetings of the American Society of Civil Engineers Chattanooga, April 20, 1939, Denver, July 25, 1940, New York, January 22, 1942, New York, January 21, 1943. The titles of these papers are given in Section 1 of the classified bibliography (133, 136, 137, 138).

The Committee on Sampling and Testing was reorganized in October 1942, when Mr. Joel D. Justin assumed the Chairmanship of the Executive Committee of the Soil Mechanics and Foundations Division, Mr. Philip C. Rutledge was appointed Chairman, and Messrs. Robert M. German, O. J. Porter, and Willard J. Turnbull became Members of the Committee on Sampling and Testing. The writer resigned as research engineer to the committee in December 1942 to engage in private work. He was appointed member of the committee, in which capacity he continued the research on sampling of subsurface materials whenever time and opportunity made it possible. During the period from December 1942 to March 1946 the research was in part supported by a stipend paid by the Graduate School of Engineering, Harvard University,

and to a large extent performed by the writer without remuneration.

The analysis of the large amount of data and preparation of a final and comprehensive report were greatly delayed by the priority of other activities during the war and later because of the cost of preparing the many figures for reproduction. In March 1946 the Corps of Engineers, through the Waterways Experiment Station in Vicksburg, offered assistance in preparation of the final report, engaged the writer to supervise the work, and entered a cooperative arrangement with the committee for editing and printing the report

The figures and final draft of the report were essentially completed in the fall of 1947, and reproduction typing was started in January 1948. Therefore, excepting minor revisions and substitutions, the report represents the status of the research at the end of the year 1947.

ACKNOWLEDGEMENTS

The research was made possible through the cooperation of many institutions, organizations, individual engineers, and in particular by the generous assistance of The Engineering Foundation, the Graduate School of Engineering of Harvard University, and the Corps of Engineers of the Department of the Army.

The Engineering Foundation made generous annual research grants to this project during the five-year period from February 1938 to December 1942. Since then some funds from continuing grants have also been allocated to the project for the purpose of printing this and preceding reports. Without the active support of the Engineering Foundation, the research could not have been initiated and carried through the years when the basic experiments were performed.

The Graduate School of Engineering provided office, secretarial, laboratory, and machine shop facilities for the research engineer, bore the cost of reproduction typing of the preliminary reports and of construction of much experimental equipment, and supported the research by a stipend paid the writer during the period from January 1943 to July 1945.

The Corps of Engineers, besides undertaking or participating in several series of experiments, provided facilities for and bore the cost of preparation and preliminary printing of the final report. Without this assistance by the Corps of Engineers, the report could not have been completed and printed in its present form.

The cooperation of various organizations and persons is acknowledged in the following paragraphs, but it is impossible to mention individually the many engineers in this country and abroad who have assisted the committee by furnishing information on sampling methods and equipment. A list of special communications and reports to the committee is found in Section 1 of the classified bibliography, whereas reprints of published reports and papers, received by the committee, are listed in their appropriate sections of the bibliography.

Special recognition and appreciation are due the first chairman of the committee, Mr. Joel D. Justin, who organized the research and obtained the cooperation of other organizations. The arrangement for assistance in preparation and printing of the final report is due to the efforts of Messrs. Frank A. Marston and Philip C. Rutledge, Chairmen, respectively, of the Executive Committee and the Committee on Sampling and Testing, and in particular to the cooperation of James H. Stratton, Member of the Executive Committee and Colonel, Corps of Engineers.

The cooperation of the Graduate School of Engineering, Harvard University, was arranged by Professor H. M. Westergaard, then Dean, and Professor A. Casagrande who also placed departmental and personal facilities and records at the disposal of the committee and its research engineer and furthered the research at every opportunity. Many practical suggestions for construction of sampling and testing equipment were contributed by Mr. Philip Grotjohan, in charge of the machine shop of the Graduate School of Engineering.

Various Divisions and Districts of the Corps of Engineers cooperated individually by furnishing detailed information on sampling methods and equipment, and the Missouri River Division, the Providence District, and the Waterways Experiment Station undertook or participated directly in experiments and development of improved sampling methods and equipment.

The Bureau of Yards and Docks, Department of the Navy, permitted experiments to be performed during sampling operations at the South Boston Dry Dock and at the Charlestown Navy Yard.

The Division of Highways, State of California, through Messrs. T. E. Stanton and O. J. Porter, furnished a one-inch piston sampler and detailed information on sampling methods and equipment developed in their department.

The Raymond Concrete Pile Company, through Mr. H. A. Mohr, has built or paid for the construction of several samplers and parts of the experimental equipment besides participating in the performance of many field tests. Mr. H. A. Mohr contributed personally to the development of new equipment by many helpful suggestions and his ever active interest in the research.

Mr. E. Pola, President of the Pleasant Valley Brick Company near Hartford, Connecticut, gave permission to perform extensive experiments in the clay pits of the company and facilitated the work by loan of laborers and equipment.

Dr. C. S. Piggot and Mr. E. A. Johnson of the Carnegie Institution of Washington permitted observations to be made during their coring experiments near Hartford, lent their equipment, and assisted in special experiments for the committee. Later they placed the results of their own experiments at the disposal of the committee.

Mr. H. C. Stetson of the Woods Hole Oceanographic Institution lent equipment and collaborated personally in experiments near Woods Hole, Massachusetts, and

also made the results of experiments with a new ocean bottom sampler available to the committee.

As already mentioned, the Waterways Experiment Station undertook the preparation and reproduction of the final report. Special recognition is due Messrs. Willard J. Turnbull and Stanley J. Johnson for a critical review of the entire manuscript and for many valuable suggestions, Messrs. Reginald A. Barron, William R. Perret, and Thomas B. Goode for reviewing sections of the report, Mr. William L. Boult and Mrs. Hilda D. Rowe for preparing the figures for reproduction; and the Reports Branch and the Reproduction Branch for final editing and printing of the report.

In conclusion the writer wishes to express his personal and sincere appreciation of the assistance rendered by the organizations and persons mentioned above and by the many engineers who contributed special information, reports, or reprints of their papers.

M. J. H.

November 1948

CONTENTS

INTRODUCTION

The soil or rock and water below the ground surface supports, exerts pressure on, or is utilized in and thereby affects the safety of nearly all civil engineering structures Technical literature contains numerous examples of costly failures which can be attributed to the action of the soil and ground water and, in the end, to the absence of or to inadequate or unreliable subsurface explorations. A careful investigation of successful projects would probably reveal an equal number of cases in which parts of the structure are over-designed, where uneconomical types of structures or unfavorable locations were chosen, and where considerable savings could have been effected if adequate foundation investigations had been made and the results properly interpreted

Before the advent of soil mechanics, foundation investigations were confined to the determination of sequence, thickness, and general character of the soil strata, and the suitability of the various strata for foundation or construction purposes was primarily determined on the basis of general or local experience Explorations were made by means of test pits or simple borings or soundings, and when samples were obtained, they were generally seriously disturbed although adequate for the purpose of identification of and simple tests on the soil With the rapid development of soil mechanics and laboratory methods for determination of the physical properties of the soils, it soon became evident that some of the physical properties of the soil may be seriously changed during sampling operations or by subsequent storage or handling of samples in the laboratory, and that unreliable or misleading results obtained when the test data were used in the analysis or design of foundation or earth structures The first task with which the Committee on Sampling and Testing was charged consisted of (1) an investigation of the causes and effects of the disturbance of soil samples, (2) a critical review of methods and equipment used for soil sampling in this country and abroad, and (3) development of improved methods and equipment for obtaining undisturbed soil samples

The experimental research and the various progress reports have been confined to the above mentioned subjects However, in planning the final report, consideration was given to the fact that undisturbed samples are not required for the solution of many common foundation and construction problems, although they generally are needed as a part of the final foundation investigations for important or unusual projects and are a prerequisite for the continued advancement of soil mechanics and foundation engineering Furthermore, other methods of subsurface exploration which are not based on obtaining samples, such as geophysical and sounding methods, have been subject to significant developments This also applies

to certain methods of exploration and sampling which should be considered although they are used primarily for other than civil engineering purposes. Therefore, it was decided to enlarge the scope of the report to include a general review of all methods used in subsurface exploration and sampling of subsurface materials, however, the main subject of the report is the securing, preservation, and handling of undisturbed soil samples

Observation of ground-water levels and performance of minor field tests, which can be considered as an integral part of the exploration or sampling operations, are discussed On the other hand, descriptions of actual field tests, such as loading and permeability tests, and special installations and methods for determination of movements and pressures of the soil and ground water, are considered to be outside the scope of this report Likewise, the discussion of examination and handling of samples in the laboratory is limited to operations required to determine the stratigraphical soil profile and the condition of the samples, and does not include actual preparation of test specimens and subsequent tests The report is divided into two main parts, subject to the delimitations mentioned above

The first part contains a review of the requirements, general procedures, and various methods of subsurface exploration and sampling In discussing the latter, stress is laid on the general principles and problems encountered rather than on details of the equipment which are presented in the second part of the report A series of summary directions for the design of sampling equipment and for sampling operations and handling of samples has been formulated However, it should be borne in mind that the systematic experiments were made in only a few types of soil, and that the recommendations, of necessity, are broad generalizations. The directions should not be applied indiscriminately, and exceptions to some of the rules are to be expected

The second part of the report contains a fairly detailed description of the equipment and methods used in obtaining samples of subsurface materials and in the preservation and handling of these samples. Some of the samplers mentioned are now considered obsolete, although they embody features which still are used or may be used again A description of these samplers is included in order to give proper credit to those who developed original ideas and designs and to prevent the expenditure of time and money on developing methods or details which already have been tried out Several tentative methods and designs are also described, they are presented, although untried, to call attention to possible new or alternative solutions of the problems encountered.

The second part of the report also contains a review of the principal sampling methods and equipment used in ocean-bottom exploration and in search for oil and minerals In some respects these methods are advanced beyond those used in subsurface exploration for civil engineering purposes, and they have been or may, under certain conditions, be used to advantage for the latter purpose.

The advantages and disadvantages of the various methods and types of equipment for boring and sampling are discussed in relation to the soil conditions Because of the great variation in the physical properties of soils, it is unlikely that a single sampling method or type of sampler, which will produce satisfactory samples under all conditions, will ever be developed On the contrary, best results will be obtained at least cost when several types of samplers are at hand and are used in accordance with the character of the soil and the purpose of the exploration, and when the operators constantly watch out for minor changes in the soil conditions and make corresponding adjustments of the equipment and sampling procedure Although general directions for the design of samplers and for their operation in various types of soils and for various purposes are given in the first part of the report, definite recommendations of specific samplers and methods, described in the second part, are not made A first-hand study of local conditions often is necessary before the final selection, and there is often a choice between alternative methods and details which still are in the process of development

Originally it was intended to add a third part to the report, in which the research methods and equipment and the principal series of experiments would be described in considerable detail, but this material would be of little interest to the practicing engineer Therefore, this third part was omitted and some of the principal test results are inserted in the first part in order to help explain the causes of disturbance of soil samples and to substantiate the recommendations made

The report is concluded with an extensive, classified bibliography on subsurface exploration, sampling of soil and rock, and allied subjects

PART I
PRINCIPLES OF EXPLORATION AND SAMPLING

CHAPTER 1
GENERAL PROCEDURE AND REQUIREMENTS

1.1 Problems and Phases of Foundation Investigations

Investigation of the distribution, type, and physical properties of subsurface materials are, in some form or other, required for the final design of most civil engineering structures These investigations are performed to obtain solutions to the following groups of problems

Foundation problems or determination of the stability and deformations of undisturbed subsurface materials under superimposed loads, in slopes and cuts, or around foundation pits and tunnels, and determination of the pressure of subsurface materials against supporting structures when such are needed.

Construction problems or determination of the extent and character of materials to be excavated or location and investigation of soil and rock deposits for use as construction materials in earth dams and fills, for road and airfield bases and surfacing, and for concrete aggregates

Ground-water problems or determination of the depth, hydrostatic pressure, flow, and composition of the ground water, and thereby the danger of seepage, underground erosion, and frost action, the influence of the water on the stability and settlement of structures, its action on various construction materials, and its suitability as a water supply

A complete foundation investigation comprises the following three more or less overlapping and interdependent phases

The stratigraphical survey or subsurface exploration and sampling The objectives of this survey are: (1) to determine the depth to and pressure of the ground water and the sequence, thickness, extent, and approximate identity of the strata of soil and rock to the required depth below the ground surface, (2) to obtain samples of the ground water, soil, and rock of a size and condition adequate for positive identification of the material and for the tests of the physical survey, and

(3) to make observations and certain incidental or minor field tests which will facilitate determination of the condition of the samples obtained and estimation of the physical properties of the materials or of their action during and after construction of the proposed structures

The physical survey or field and laboratory tests for the purpose of determining the physical properties of the materials to the extent required for an estimate of the behavior of the materials under the conditions imposed by the proposed structure It is emphasized that the survey cannot be limited to determination of the physical properties of a few samples but requires, in many cases, a reliable estimate of the average values for the entire stratum or strata under investigation In other cases, especially for stability problems, it is necessary to locate the weakest or critical strata and determine their physical properties In case of erratic soil conditions or soils with secondary structure and when satisfactory samples cannot be obtained, recourse is often taken to special or major field tests on the soil in situ

The evaluation of the data obtained in the stratigraphical and physical surveys and the formulation of definite solutions to the problems mentioned in the first part of this section. This evaluation may be simply an estimate based on the personal experience of the engineer, or on general empirical rules or regional ordinances, or it may require more or less involved computations based on the theories of soil mechanics When soil conditions or the stresses created by the proposed structure are so complicated that a detailed mathematical analysis of the problem is too difficult or unreliable, recourse is again taken to observation of completed structures, special field tests on the soil in situ, or to model tests

This report deals only with the first phase of the foundation investigation or the stratigraphical survey and appurtenant observations and minor field tests However, the methods and requirements of the two other phases must constantly be kept in mind, since they and the general character of the problem to a large extent govern the care and details required and the methods used in the stratigraphical survey

1.2 General Definitions

Before discussing the general procedure and requirements in subsurface explorations, it is desirable to establish broad classifications of the methods used and results obtained The definitions and classifications presented in this section and also the foregoing and following sections are summarized in Table 1. These classifications are intended only for a general orientation, more detailed classifications and tables will be found in Chapters 2, 4, 5, and 6.

In this report the term "stratigraphical survey" is used to designate all field operations, whereas "exploration" refers primarily to the determination of

TABLE 1 - GENERAL DEFINITIONS AND CLASSIFICATIONS

	Types of Problems	FOUNDATION INVESTIGATIONS	Phases of Investigation		
Stability of subsurface materials Deformation and consolidation Pressure on supporting structures	Foundation Problems		Stratigraph Survey	Exploration Sampling Identification	Stratigraphical Profiles Rock-line, rough, or detailed soil profiles, limited physical profiles
Excavation of subsurface material Use of excavated material	Construction Problems		Physical Survey	Laboratory Tests Major Field Tests	Physical Profiles Rough or detailed data on variation of physical properties with depth
Flow and action of ground water Quantity and use of ground water	Ground Water Problems		Evaluation of Data	Empirical Rules Soil Mechanics	Final Design Based on stratigraphical and physical profiles latter often estimated

	Types of Samples	SAMPLES AND SAMPLERS	Types of Samplers	
Soil from various strata mixed or some soil constituents removed or foreign materials added to sample	Non-Representative Samples		Exploration Samplers	Augers bailers, sandpumps slit and cup samplers or sampling tubes with a longitudinal or circumferential slit Non-representative and representative samples
Soil structure disturbed or change in water content or void ratio but no change in the soil constituents	Representative Samples		Drive Samplers	Sampling tubes driven without rotation or chopping, displaced soil pushed aside Open drive samplers and piston samplers Represent and undisturbed samples
No disturbance of soil structure No change in water content void ratio, or chemical composition	Undisturbed Samples		Core Boring Samplers	Rotation or chopping action of sampler displaced material ground up and removed by circulating water or drilling fluid Representative or undisturbed samples

	Principal Types of Exploration	STRATIGRAPHICAL SURVEY OR SUBSURFACE EXPLORATIONS	Phases or Sequence of Operations	
Geophysical methods soil sounding yielding limited physical profiles Borings without taking representative samples of principal strata	Indirect Methods		Fact Finding and Geological Survey	Gathering of data on foundation experience and results of previous explorations at site and vicinity In case of large projects site survey by an engineer-geologist
			Reconnaissance Explorations	Semi-direct methods with or without indirect methods Rough ground water observations in permeable strata Required for all projects Sufficient for many standard structures, small loads simple soil conditions
Borings - Changes in material detected by action of tools or non-representative samples Identification by representative samples	Semi-Direct Methods		Detailed Explorations	Continuous undist samples of small diameter or large repres samples of pertinent strata Ground water observations in fairly pervious strata Sufficient for common foundation problems all construction problems
Test pits, trenches drifts other accessible explorations or borings yielding fairly continuous representative or undisturbed samples	Direct Methods		Special Explorations Undisturbed Sampling	Large undisturbed samples in borings or in accessible explorations Ground water levels and pressures in impermeable strata Required for structures unusual size and character and for difficult foundation conditions

The logical sequence of operations for exploration of a large area in virgin territory is indicated by the four phases or steps but some of these phases may often be omitted or combined These phases also show the details required with increasing importance of the structure departure from accepted design standards and the foundation difficulties encountered

the depths to and approximate identity of the subsurface strata, and to the methods used in providing access to these strata for the purpose of obtaining samples or of examining the strata in situ Likewise, the term "boring" refers only to the bore hole and the methods of advancing such holes Various methods of sampling may be used in connection with a single method of boring and vice versa. When a bore hole is advanced entirely by sampling, the method of boring or exploration will be called continuous sampling and further designated by the method of sampling In practice, the term "exploration" is occasionally used to cover all field operations, and this all-inclusive meaning is retained in this report for a few commonly used terms, such as reconnaissance exploration and detailed exploration

The samples obtained may be classified in accordance with the condition or disturbance of the material, or roughly in the following three groups

Non-representative samples consist of a mixture of materials from various soil or rock layers or are samples from which some mineral constituents have been removed or exchanged by washing and sedimentation These samples are also called "wash samples" or "wet samples" because they often are obtained from material which has been washed or bailed out of a bore hole and allowed to settle in a sump at the ground surface Such samples do not represent the material actually found at the bottom of the bore hole and are unsuitable for positive identification of the material and for laboratory tests, but they often permit a preliminary classification and determination of depths at which major changes in the subsurface strata occur and at which representative or undisturbed samples should be obtained

Representative samples contain all the mineral constituents of the strata from which they are taken and have not been contaminated by material from other strata or by chemical changes, but the soil structure is seriously disturbed and the water content may be changed These samples are suitable for general classification tests and positive identification of the material, but they are not suitable for major laboratory tests and determination of the structural properties of the material in situ These samples are often called "dry samples" in contrast to "wet samples", but this term is very misleading since the samples are not dry but usually have a water content a little above or below that of the material from which they are taken

Undisturbed samples may be defined broadly as samples in which the material has been subjected to so little disturbance that it is suitable for all laboratory tests and thereby for approximate determination of the strength, consolidation, and permeability characteristics and other physical properties of the material in situ The term is to some extent misleading since it is impossible to obtain a truly undisturbed sample, but it is firmly established in engineering terminology and has therefore been retained The term "undistorted sample", proposed by **H. A. Mohr (341)***,

* Numbers in parentheses refer to the classified bibliography

in many cases better expresses the actual condition of the sample Many samples which visually appear to be undisturbed have actually been subjected to considerable disturbance of the soil structure A detailed discussion of the requirements for "practical undisturbed" samples and of the various types of disturbance and their influence on the physical properties of the soil is presented in Chapter 6

Samples of soil close to the ground surface or to the bottom or walls of test pits, tunnels, and other accessible explorations may be obtained by digging or carving, or by methods similar to those used for obtaining samples in bore holes Many types of samplers are used for the latter purpose and they may be classified in the following three principal groups

Exploration samplers. This term is proposed as a group name for augers, bailers, sandpumps, slit tube, and cup samplers, which are used both for advancing the bore hole and for obtaining samples of cohesionless materials and soft to medium stiff cohesive soils The samples obtained are seriously disturbed and some mixing of adjacent soil layers may occur so that they cannot always be considered as truly representative samples

Drive samplers consist of a tube which is forced into the soil in a unilateral motion An amount of soil corresponding to the wall thickness of the tube is thereby pushed aside and causes compaction or plastic deformations of the surrounding soil The drive samplers may be divided into two groups, **open samplers and piston samplers.** The tube of the former is always open at its lower end, and soil enters the sampler as soon as it is forced into the ground On the other hand, the tube of the latter group is temporarily closed with a plug or piston, so that the sampler can be pushed through soil of which samples are not desired, and the piston can be released or retracted when a sample is to be taken Both representative and undisturbed samples of soils can be obtained according to the construction of the sampler and the care used in the sampling operation

Core boring samplers or core barrels are, in contrast to drive samplers, advanced by a chopping action of the barrel or by rotation while being forced into the ground The material displaced by the walls of the barrel is not pushed aside but is ground up and then removed by circulating water or drilling fluid Both representative and undisturbed samples can be obtained according to the construction and operation of the core barrel and the character of the material. Core barrels are primarily suited for use in stiff, dense, or partially cemented soils and in rock.

Bearing in mind that subsurface materials can be identified positively only by means of representative or undisturbed samples or by examination in situ, the methods of subsurface exploration may be classified in the following three groups·

Indirect methods comprise geophysical methods and sounding methods The depths to the principal strata are determined by surface measurement of changes in certain physical properties, such as electrical resistivity, seismic wave velocity, or resistance to the penetration of a sounding rod Samples are not obtained, and

positive identification of the strata requires correlation with the results of semi-direct or direct methods of exploration within the area under investigation Borings in which representative samples are not obtained may also be classified as indirect methods

Semi-direct methods are common boring and drilling methods combined with intermittent sampling The depths to the principal strata are determined by the rate of progress, the "feel" or resistance to the advance of the boring tools, or by means of non-representative samples obtained in the course of the boring operations. The major strata can be identified approximately but not definitely by these observations and samples. However, the borings provide access to the strata, so that representative or undisturbed samples can be obtained whenever a change in the character of the material has been observed. In general, only the depths to strata of appreciable thickness and at which major changes in the character of the subsurface materials occur can be determined reliably by the semi-direct methods

Direct methods are boring and sampling methods which provide practically continuous, representative or undisturbed samples, and all accessible explorations, such as test pits, trenches, large-diameter borings, shafts, and tunnels, which permit direct examination and mapping of the strata in situ. The direct methods of exploration provide the most detailed and reliable data of all methods.

The results obtained by the stratigraphical survey are generally presented as a plot showing surface elevation and depths to or elevations of the various strata. When the plot, in addition to these depths, shows only the identity of the strata, it is called a **stratigraphical profile or simple soil profile.** When the plot also shows variations in physical properties or coefficients, as determined during the physical survey, it is called a **physical soil profile.** Profiles obtained by indirect methods of exploration are limited physical profiles which may be transformed into stratigraphical profiles through correlation with other methods of exploration.

The term "profile" is used even if the plot is one-dimensional and only shows the sequence of the strata along a vertical or inclined line, as determined by a single boring or probing True profiles, or two-dimensional profiles, can be obtained directly by some geophysical methods and in some accessible explorations and are then often called **continuous profiles.** However, two-dimensional profiles are generally determined by interpolation between several one-dimensional profiles. Various methods of plotting the profiles are discussed in Section 7.7. The profiles may, according to the details shown, be divided into the following three groups·

Rock-line profiles show only surface elevations and depths to rock or, in some cases, to strata of exceptional bearing capacity such as hardpan, hard clay, very dense sand and gravel, etc. These profiles can often be obtained by indirect methods of exploration.

Rough soil profiles show the depths to principal subsurface strata and also the depths to free ground-water level, in case the exploration is extended below this

level. Rough soil profiles are obtained by semi-direct methods of exploration or small-diameter borings in which each of the major strata is identified by means of representative samples.

Detailed soil profiles show not only the major strata but also the dip of the strata, thin strata and seams, faults, shear planes, and other details which can be obtained only by means of direct methods of exploration In addition to the free groundwater level, detailed profiles should also show the piezometric pressure levels at various depths or at least in fairly porous, water-bearing strata Profiles showing the stratifications and gradual changes in the character of the soil in considerable detail can be obtained by some sounding methods, but the soil in the various strata cannot be identified by these methods alone

1.3 General Considerations

Two requirements should always be observed in planning subsurface explorations. The first of these requirements is reliability of the work performed. Carelessness or lack of experience may produce inconclusive and often completely misleading results, which may not only prevent selection of the most economical location and design of the proposed structure but may often cause expensive changes in the adopted design or require the use of costly construction methods. The performance of subsurface explorations should be entrusted only to engineers, contractors, and drilling crews of proven experience and reliability.

The second requirement is timeliness. The value of foundation investigations is greatly decreased if they are not completed before major decisions, which may be influenced by the results of the investigations, are made All too often, the explorations are postponed until changes in the location and general design of the structure can no longer be made or time limitations prevent performance of desirable laboratory tests. It must be borne in mind that certain soil tests require considerable time and cannot be accelerated without seriously impairing the value or reliability of the test results.

Detailed advance planning of subsurface explorations for large projects is often difficult, since the spacing and depth of profiles or borings and the methods and equipment to be used depend not only on the nature of the project and general purpose of the investigation but to a still larger degree on the subsurface conditions themselves. The exploration is often a series of progressive approximations in which each step is determined by the results of the already completed part of the exploration. It is therefore difficult to formulate definite rules of procedure, but as a guide and for the purpose of discussion, subsurface explorations may be divided into the following four steps or phases:

(1) Fact finding and geological survey
(2) Reconnaissance or general exploration
(3) Detailed exploration -- small undisturbed samples
(4) Special explorations -- large undisturbed samples

These four steps, which will be discussed in some detail in the following sections, indicate the logical sequence of large-scale operations in virgin territory. The fact finding and geological survey serves as a basis for preliminary planning of the actual exploration The reconnaissance exploration furnishes data for a more detailed geological survey and for the required spacing and depth of and the methods and equipment to be used in detailed explorations, if required Results of the detailed exploration, in turn, will indicate the need of and best location for special borings or test pits, the depths to strata from which large undisturbed samples are required, and the most advantageous methods of advancing test pits or borings and obtaining undisturbed samples

The above mentioned four phases or steps also indicate the details required with increasing importance of the project or with the foundation difficulties encountered; it is emphasized that one or two of these classes of exploration are sufficient in the majority of cases Even in large-scale operations it is not always possible or desirable to adhere strictly to the above mentioned sequence of operations Reconnaissance explorations may be omitted in areas where the soil conditions already are fairly well known and it may, in many cases, be advantageous to combine the detailed and special explorations by taking practically continuous undisturbed samples of such a diameter that they can be used for all laboratory tests.

When the site of exploration is difficult of access or at considerable distance from the laboratory, it may be desirable or necessary to complete all boring and sampling operations before any of the samples can be examined and tested in the laboratory The depth of the borings should then be extended, their spacing decreased, and the number of undisturbed samples taken increased, in order to cover unforeseen contingencies The additional cost involved may be less than that of moving drilling equipment and personnel to the site for a second or third time

1.4 Fact Finding and Geological Survey

The natural first step in the foundation investigation of a given site is a gathering and digest of available data on subsurface conditions and the behavior of other structures in the vicinity of the proposed project Such data facilitate the planning and will often decrease the required extent of the actual exploration Valuable data on subsurface conditions can often be obtained from maps and publications of Federal, State and institutional geological surveys, and from the Bureau of Public Roads and State Highway Departments. Detailed data on foundation conditions in highly developed areas may be found in technical periodicals and reports or obtained from local building commissions, engineers, and contractors. Efforts are currently being made to assemble and publish available data on foundation conditions in several regions.

A preliminary geological survey, based on outcroppings and other surface indications, is generally made for large projects in virgin territory. From the data

thereby obtained, and especially when it is supplemented by the results of reconnaissance explorations, an engineer-geologist will often be able to sketch the general geological structure of the site, estimate the character and depth of the overburden, and indicate the location of possible buried channels, faults, etc., where borings first should be made. In accordance with principles recently established by **Belcher, Gregg and Woods** (202, 901), coupled with a general knowledge of the geology and climate of the region, an estimate of the character of surface deposits can be made from a study of stereoscopic aerial photographs. This method is particularly valuable for preliminary planning of highways and airfields and for location of soil deposits which may be suitable for construction materials. Aerial photographs also greatly facilitate the detection of slide areas, buried channels, faults, and other subsurface irregularities.

1.5 Reconnaissance or General Exploration

The principal objective of reconnaissance or general explorations is to obtain rough soil profiles and representative samples of the principal strata or, in partial substitution thereof, to obtain rock-line profiles or limited physical profiles by means of indirect methods of exploration. The free ground-water levels should be determined if reached by the required depth of exploration.

Auger borings, wash borings or displacement borings with small piston or cup samplers are commonly used and representative samples from 1 in. to 2 in. in diameter obtained. Geophysical methods are often used in the preliminary exploration of sites for large projects, since they are rapid and relatively cheap and facilitate detection of subsurface irregularities which may be missed by individual borings. Sounding methods are being used on an increasing scale in the exploration of sites for small and medium-sized projects and furnish data on the physical properties of the soil which, through proper correlations, can be used directly in the design of the structure. However, these indirect methods of exploration should always be supplemented by borings in which representative samples are obtained, unless adequate correlations already have been made in the area under investigation.

These explorations furnish data for the planning of detailed and special explorations of sites for large and important projects. They are in themselves sufficient for solution of many construction problems and especially those concerning excavation of materials. They are also adequate for solving many simple foundation and stability problems: (1) when the loads are small and the factor of safety is large, (2) when the structure is to be founded on or the design is governed solely by the depth to bedrock or strata of high bearing capacity; and (3) when structures of ordinary character are built in localities where the properties of prevalent soil types are known from long practical experience and this experience has been summarized in empirical rules or building codes. The data obtained by some sounding methods may be adequate for the final design when satisfactory correlations are available for similar soil conditions and structures.

1.6 Detailed Explorations

The purpose of these explorations is to obtain detailed soil profiles and relatively undisturbed samples with a diameter of 2 to 3 in. or to obtain larger and fairly continuous, representative samples of deposits considered for use as construction materials. Appreciable excess hydrostatic pressures in pervious strata should be determined in addition to the free ground-water level or levels.

Test pits and trenches are often used in very shallow explorations, whereas practically continuous sampling by means of open drive samplers, piston samplers, or core boring samplers is used for deeper explorations. Strata of which detailed soil profiles are not required are penetrated by means of one of the various boring methods. In cases where it is difficult to obtain satisfactory samples, the borings are often supplemented by penetration or sounding tests.

Detailed explorations are adequate for the final investigation of deposits to be used as construction materials. Unless it is preferred to combine detailed and special explorations by taking continuous, large-diameter samples, detailed explorations are required in the foundation investigation for the majority of large and important projects, they are in themselves sufficient for the solution of many common foundation and stability problems, especially when the variations of physical properties within individual strata are so great that it is more important to determine reliable averages than accurate values for a particular depth or sample. With the improvement of small-diameter samplers, detailed explorations are being used as a compromise between the relatively inexpensive but inadequate general explorations and the more expensive special explorations in which large-diameter, undisturbed samples are obtained.

1.7 Special Explorations and Undisturbed Sampling

The object of this phase of subsurface exploration is to obtain from critical strata undisturbed samples, 4 in. or more in diameter, which are suitable for special laboratory tests, or to provide large-diameter borings for special field tests or accessible explorations for inspection, mapping, sampling, and testing the materials in situ. Determination of pore-water pressures in critical strata of low permeability may be required.

The bore holes are advanced to the critical strata by means of wash boring, power-driven augers, percussion or rotary drilling according to soil conditions and available equipment. Samples in borings are obtained with large drive samplers or core barrels. Accessible borings, test pits, or tunnels are used to moderate depths when soil conditions permit their construction, and samples are then obtained by advance trimming or block sampling methods. Piezometers or hydrostatic pressure cells are used for determination of the pore-water pressures.

Special explorations are required for the solution of foundation problems

involving either structures of exceptional size and character or difficult foundation and ground-water conditions. Large-diameter samples are needed for accurate determination of the consolidation characteristics of cohesive soils, for certain direct and torsion shearing tests, and when several test specimens for unconfined or triaxial compression tests are to be cut from the same soil layer or depth so that several tests can be performed on identical soil types.

1.8 Location and Spacing of Borings

At the completion of the survey, the location and spacing of geophysical profiles, soundings, and borings should be such that the soil profiles obtained will permit a reasonably accurate estimate of the extent and character of the intervening soil or rock masses and will disclose important irregularities in subsurface conditions.

In exploration of large sites, the first borings or geophysical profiles should not be located in accordance with a rigid pattern or spacing but in such a manner that they will furnish the most necessary data for completion of the general geological survey and thereby facilitate further planning of the exploration. When soil conditions are found to be uniform, a spacing of 400 to 500 ft for the borings will often be adequate; this spacing may be decreased later by intermediate borings where required. A regular spacing of 100 ft, or one bore hole for each 10,000 sq ft of area, is often used in explorations for highways, airfields, and some large dams, especially when results of the exploration cannot be evaluated in detail as the work progresses. The spacing must be decreased to 50 ft or 25 ft, and occasionally to even smaller values when erratic subsurface conditions are encountered, but a spacing of 25 ft will generally provide adequate information even for erratic conditions. Such conditions are likely to exist along rivers, lakes, estuaries, and in many parts of glaciated and mountainous regions.

The great majority of borings are vertical, but inclined borings may be used to advantage in exploration of inclined strata and various subsurface irregularities, such as lenses, buried channels, cavities, and fault zones. Inclined borings are also used when surface obstructions prevent use of vertical holes, as in obtaining soil profiles under existing structures or deep and swift flowing rivers. Each inclined bore hole furnishes information on variations in subsurface conditions in both a vertical and horizontal direction. Inclined bore holes have occasionally been used instead of vertical holes for systematic exploration of dam sites and with such spacing that the top of one bore hole is vertically above the bottom of an adjacent hole, **Lynn and Rhoades (336).**

Borings for exploration of narrow or elongated areas should not all be located in a single straight line, but there should be a sufficient number of borings outside the main line to determine the dip and strike of the subsurface strata and irregularities in profiles at right angle to the axis of the area.

In exploration of sites for dams, embankments, bridges, and similar structures,

borings should also be made outside the actual site, which has been chosen on the basis of surface conditions and requirements, in order to determine whether a shift in location may be advantageous when subsurface conditions also are taken into consideration.

In exploration of areas of limited extent, as for individual buildings and bridge piers, the initial borings should preferably be located close to the corners of the area, and the number of borings should not be less than three unless subsurface conditions are known to be very uniform. These preliminary borings must be supplemented by intermediate borings as required by the extent of the area and the subsurface conditions encountered

Borings inside an area, which is to be enclosed by a cofferdam or caisson and unwatered, may become a source of additional inflow of water and thereby increase the difficulties of unwatering In such cases it is advisable to locate all the borings outside the area to be unwatered, at least, all bore holes within or close to this area should be carefully backfilled with impermeable soil. On the other hand, in exploration of sites for dams to be founded on rock, some of the bore holes are often so located that they later can be used for grouting operations

1.9 Depth of Exploration

The required depth of exploration depends to some extent on the size and type of the proposed structure and on certain design considerations -- such as safety against foundation failure, excessive settlement, seepage, earth pressure, etc. -- but it depends to a still larger degree on the character and sequence of the subsurface strata Unless the general stratigraphy of the area is known, it is difficult to estimate the required depth, and it is very important that reconnaissance explorations or the first of a group of borings be carried to fully adequate depths.

General rules.- The borings should be extended to strata of adequate bearing capacity and should penetrate all deposits which are unsuitable for foundation purposes -- such as unconsolidated fill, peat, organic silt, and very soft and compressible clay. The soft strata should be penetrated even when they are covered with a surface layer of higher bearing capacity.

When structures are to be founded on clay and other materials with adequate strength to support the structure but subject to considerable consolidation by an increase in the load, the borings should penetrate the compressible strata or be extended to such a depth that the stress increase for still deeper strata is reduced to values so small that the corresponding consolidation of these strata will not materially influence the settlement of the proposed structure.

Except in case of very heavy loads or when seepage or other considerations are governing -- see paragraph on dams and levees -- the borings may be stopped when rock is encountered or after a short penetration into strata of exceptional

bearing capacity and stiffness, provided it is known from explorations in the vicinity or the general stratigraphy of the area that these strata have adequate thickness or are underlain by still stronger formations. When these conditions are not fulfilled, some of the borings must be extended until it has been established that the still strata have adequate thickness irrespective of the character of the underlying material.

When the structure is to be founded on rock, it must be verified that bedrock and not boulders have been encountered, and it is advisable to extend one or more borings from 10 to 20 ft into sound rock in order to determine the extent and character of the weathered zone of the rock

In regions where rock or strata of exceptional bearing capacity are found at relatively shallow depths -- say from 100 to 150 ft -- it is advisable to extend at least one of the borings to such strata, even when other considerations may indicate that a smaller depth would be sufficient The additional information thereby obtained is valuable insurance against unexpected developments and against overlooking foundation methods and types which may be more economical than those first considered

Specific requirements and simple rules for estimating the required depth of reconnaissance explorations or initial borings for various types of structures are reviewed in the following paragraphs. It is strongly emphasized that these rules should be considered only as a very rough guide for the initial estimate and that they are subordinate to the general rules given above. The depth requirements should be reconsidered when results of the first borings are available, and it is often possible to reduce the depth of subsequent borings or to confine detailed and special explorations to particular strata

Foundation structures (Fig. 1A).- Safety against excessive settlements and particularly differential settlements usually governs the design of foundation structures and the required depth of exploration. Settlements of adjacent structures, caused by the proposed structure, must be taken into consideration.

One of the first proposed and still used rules for estimating the required depth of exploration, D, below a loaded rectangular area is,

$$D = C\,B$$

in which the coefficient C is given values ranging from 1.0 to 2.0 and B variously is specified as the average diameter or the minimum width of the area. The German Committee on Foundation Investigations (315) proposed in its Manual of 1937 a series of rules which in condensed and slightly transcribed form may be expressed as follows:

Squares and Short Rectangles	$L < 2B$	$D = 0\ 8\ p\ B_a$
Long Rectangles and Strips	$L > 2B$	$D = 1.0\ p\ B$

where L is the length and B the width of a rectangular area or strip; B_a is the average diameter of a short rectangular or irregular area but is not definitely defined. It is further specified that the unit load, p kg/cm^2, should not be less than

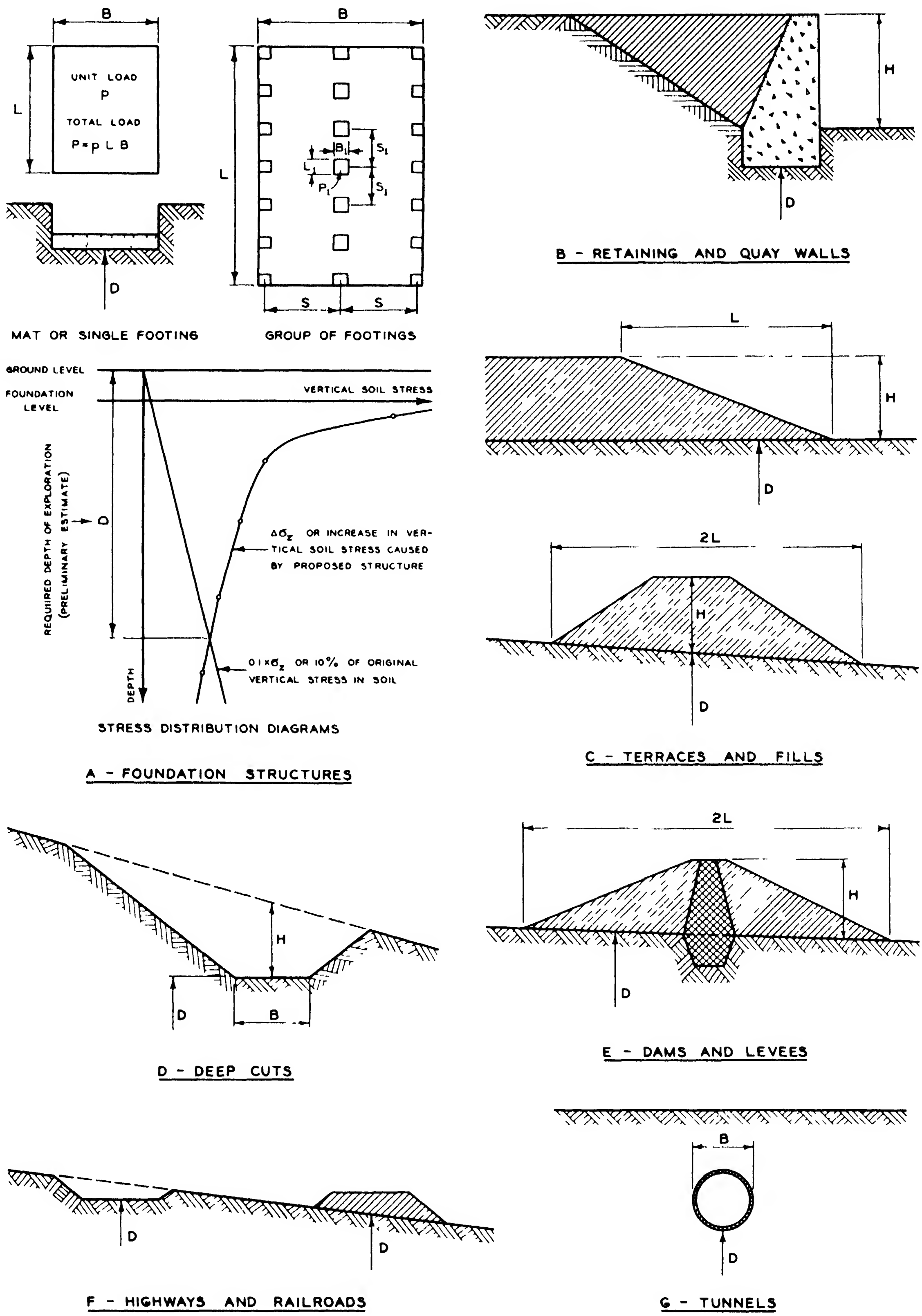

FIG 1 - REQUIRED DEPTH OF EXPLORATION

$1.0\ kg/cm^2$ or greater than $3.0\ kg/cm^2$, and that the depth of exploration, D, should never be less than 10 m below the actual foundation level unless rock is encountered. The width, B, and the average diameter, B_a, refer normally to the entire loaded area, and p is therefore the average unit load on this area and not the actual footing pressure. Only when the spacing of the footings is very great may the rules be applied to a single footing, but the critical spacing is not defined; however, **Brennecke and Lohmeyer** (206) suggest that the rules may be applied to a single footing or strip instead of the entire loaded area when the spacing, S, of the footings or strip loads is greater than 5B.

Except for the requirement that the depth of exploration should be never less than 10 m unless rock or strata of exceptional bearing capacity are encountered, these rules have been subject to considerable criticism, because they do not take properly into consideration the shape of the loaded area, load intensities and distribution, and the character and depth of the strata at which exploration is terminated. Much more reliable estimates of the required depth of exploration are obtained by computing the approximate stress distribution diagram for a vertical line through the center of the loaded area, or the center of the footing with the greatest load, and then by means of this diagram determining the depth at which the increase in vertical stress, caused by the proposed structure, is reduced to a value below which material consolidation of the soil will not occur.

For preliminary estimates, the Geotechnical Institute of Belgium -- personal communication by **E. De Beer**, Director -- has recently introduced the general rule that the above mentioned increase of vertical soil stresses at the required minimum depth of exploration shall not exceed 10 percent of the original vertical stress at this depth. This rule is easy to remember and apply, Fig 1A, and seems to give reasonable results in many cases, however, a single rule cannot cover all the varied conditions encountered. The stiffness and coefficient of compressibility of the strata, the relation of current soil pressure to preconsolidation pressure, and the sensitivity of the proposed structure to settlements must be taken into consideration in the final determination of the limiting stress increase at the required depth of exploration. It is again emphasized that all the above mentioned specific rules are subordinate to the general rules enumerated in the first part of this section.

Retaining and quay walls (Fig. 1B).- Safety against foundation failure is usually governing, but the influence of settlements may also have to be considered. Explorations should be extended to depths beyond which it is unlikely that surfaces of failure or sliding will occur. Such surfaces tend to follow the weaker strata, even when such strata are found at considerable depth. Explorations should therefore be continued until firm strata are encountered and should be extended into such strata for a distance sufficient to verify that these strata are of adequate thickness For preliminary estimates a depth $D = 0.75$ to $1.5\ H$ below the bottom of the wall or end bearing piles, where H is the net height of the wall, is suggested. This depth may have to be increased to $D = 2H$ or more when the wall is founded on thick, compressible strata which may cause excessive settlements and tipping of the wall,

especially when the backfill is not a replacement of excavated material but represents an additional load on the subsoil.

Terraces and fills (Fig. 1C).- Safety against foundation failure is usually governing, although settlements caused by consolidation of the subsoil may have to be considered in some cases Explorations should be extended to depths beyond which surfaces of failure and sliding are unlikely to occur. Maximum shearing stresses are encountered approximately at a depth D = 1.25 L for terraces and D = 0.5 L for triangular fills, where L is the average horizontal length of the slope. Except when slopes are very flat, it is suggested that these depths may be used for preliminary estimates of the required depth of exploration. A surface of sliding may occur at still greater depths, and objectionable consolidation and settlements may take place when soft materials are encountered at the above mentioned depths, in which case the exploration should be continued until firm strata of adequate thickness are reached.

Deep cuts (Fig. 1D).- Stability of the slopes is governing. The soil below a cut is subjected to a double terrace loading, but the depth of a probable surface of sliding is limited by the bottom width, B, of the cut. When this width is relatively small compared to the depth, H, of the cut, the required depth of exploration will be smaller than for a true terrace loading For preliminary estimates a depth of exploration D = 0.75 B to 1.0 B is suggested unless the depth determined on basis of a true terrace loading is smaller. When the bottom of the cut is below the ground-water level, the stability may be seriously affected by uplift and seepage, and the extent of pervious strata and the pore-water pressures in such strata should therefore be fully explored On the other hand, when the cut is above the ground-water level and in stable materials, and especially when there is a definite increase in the strength of the soil with depth, exploration to a depth of 6 to 10 ft below the cut may often be sufficient, as in normal highway explorations.

Dams and levees (Fig. 1E).- Safety against foundation failure and seepage is governing. Seepage conditions control not only loss of water but also uplift under and beyond the structure and thereby influence the danger of piping and complete foundation failure. Borings should therefore penetrate not only soft and unstable soils but also permeable materials, and they should be extended to such depths that seepage and hydrostatic pressures can be estimated with reasonable accuracy. It should be noted that seepage and uplift depend not only on soil conditions below the structure but also on those below the inundated area.

For preliminary estimates depths of exploration D = L for levees and earth dams and D = 1 5 H to 2 0 H for small concrete dams, where 2L is the bottom width and H the net height, are tentatively suggested. The borings may be stopped after a penetration of 10 to 20 ft into strong and tight strata, provided the number of borings is sufficient to verify the continuity of such strata under the inundated area. In case of large dams, rock will often be encountered within the above suggested depths, but the borings should be extended for a distance sufficient to establish the

character and stratigraphy of the rock foundation In general, the required depth of exploration for large dams is governed by the character and sequence of subsurface formations to a greater extent than for other structures

Highways, railroads, and airfields (Fig. 1F).- Borings should penetrate the weathered strata and reach a depth sufficient to disclose the general stability and drainage conditions and the danger of frost action Excepting major fills and cuts, a depth of exploration -- measured from original ground surface in fills and from finished grade in cuts -- of D = 3 to 5 ft for light loads and D = 6 to 10 ft for heavy loads represents current practice and is usually sufficient, but strata of unsatisfactory character should, as always, be fully explored.

Tunnels (Fig. 1G).- Stability of the materials and the pressure they exert against the tunnel lining are the governing considerations Based on current methods of stability analysis -- **Terzaghi (972, 973) and Housel (936)** -- it is suggested that the preliminary explorations be extended to a depth D = B below the invert elevation, where B is the gross width of the tunnel If the soil conditions are unfavorable at this depth, the borings should be extended to determine whether a lowering of the tunnel grade will be more economical Greater depths of exploration may also be required when the tunnel is to be built in materials which are subject to considerable swelling.

1.10 Sample Requirements

The required condition and the quantity or dimensions of samples to be obtained during various phases of the subsurface exploration and for various groups of laboratory tests are summarized in Table 2 Major physical tests are still in development and continuously undergoing changes, and the requirements for samples for such tests therefore depend to a considerable extent on the methods used and equipment available in the laboratory in which the tests are to be performed.

In reconnaissance borings representative samples with a volume of at least 1/5 pt, and preferable 1/2 pt, should be obtained from each distinctive stratum, in thick and apparently uniform strata it is advisable to take such samples at intervals of not more than 5 ft Fairly continuous samples with a diameter of about 1 in. are obtained by some methods of exploration -- small piston samplers -- and are satisfactory for reconnaissance explorations.

In detailed explorations practically continuous samples should be obtained, with the possible exception of surface deposits which obviously are unsuitable for foundation or construction purposes. Samples with a diameter of about 2 in. are generally satisfactory for foundation investigations, but 3-in sampling tubes are often used and furnish less disturbed samples and more reliable test results. When undisturbed tube samples of very soft soils or cohesionless soils are too difficult to obtain, representative samples with a volume of 1 to 2 qt should be taken of the particular strata so that tests on remolded soil may be performed. Still larger

TABLE 2 - SAMPLE REQUIREMENTS

PHASE OF EXPLOR.		TYPE OF TEST	CONDITION OF SAMPLE	QUANTITY OF SOIL OR WATER OR DIAMETER OF SAMPLE
Reconnais. Explorat		Visual Classification Occasionally approx Water Content, Limits	Repres	Augers, cup, or 1 to 2 in. samples Preserve at least 1/5 pint and preferably 1/2 pint in case of tests
Detailed Exploration Minor Physical Tests		Liquid and Plastic Limits Mechanical Analysis Specific Gravity	Repres.	Fine-grained soils 1/2 pint minim Mechan analysis of coarse-grained to gravelly soils 1 pint to 2 quarts
		Water Content Unit Weight	No vol change	1-3/4 to 2 in. samples usually adequate, 2-1/8 to 2-7/8 in. samples often used In test pits 3 to 4 in samples or field volume tests plus 1 to 2 quarts representative sample of coarse-grained to gravelly soils
		Unconfined Compression Direct Shear, Double, Rd Slicing, Partial Drying	Undist	
Special Explorations Major Physical Tests		Permeability Consolidation Triaxial Compression	Undist	2 in samples occasionally used but 2-7/8 in diam advisable minimum and 4 to 6 in diam preferable
		Multiple Compres Tests Direct Shear, Single, Sq. Torsion Shear, Ring	Undist	4-3/4 in diam advisable minimum 5 to 6 in diam often used. In test pits 5 to 8 in round or 10 in. cubes
Construction Materials	Exploration	Mechanical Analysis Compaction and CBR Tests Triaxial Compression Concrete Aggregate Tests	Repres or Composite Repres	From single strata or holes 100 lb to 200 lb Composite sample for a complete series of tests 500 lb. Samples for aggregates see text
	Control	Dry Density, Water Cont California Bearing Ratio Triaxial Compression	Undist	Density 2 to 4 in diam. samples or field volume tests Others 5 in. min. diam., CBR mold, or 10 in. cubes
Water		Chemical Analysis Bacteriological Analysis	Repres	1 quart to 1 gallon depending on laboratory method and equipment
Rock Drilling		Visual Inspection Mineralogical Tests Compression, Shear Porosity, Permeability	Undist	Minim 7/8 or 1-1/8 in (EX, AX) 1-5/8 or 2-1/8 in. (BX, NX) preferred because of better recovery In soft or broken rock 3 to 6 in. diam.

diameters and quantities of representative samples are required in the detailed explorations of materials to be used for construction purposes; see Table 2 and the further discussion at the end of this section.

Some of the major physical tests, such as permeability and consolidation tests, are occasionally performed on samples about 2 in in diameter, but a sample diameter of about 2-7/8 in , as taken with a 3-in OD thin-wall sampler, is the advisable minimum for this purpose. Undisturbed samples 4-1/4 in. to 5-3/4 in in diameter are required by some soils laboratories for major physical tests and are, in general, to be preferred, since the influence of the surface disturbance is decreased thereby and the test specimen may be prepared from the central and least disturbed part of the sample Larger samples also permit preparation of several smaller test specimens from a single soil layer in a section of the sample and the consequent performance of multiple unconfined or triaxial compression tests on the same soil but with varying testing conditions

When large undisturbed samples are taken, it is advisable also to preserve small representative samples of at least 1/2 pt from each distinctive stratum. These samples may be composed of material obtained by trimming the larger samples or, if necessary, they may be cut from the top or bottom of the large samples. In test pits small representative or undisturbed samples may be taken at the same levels and close to the large samples Small samples permit laboratory examination and classification tests to be performed without breaking the seals of the large undisturbed samples Routine laboratory work is thereby facilitated, the danger of disturbing the large samples is decreased, and additional data are obtained for the proper planning of the tests on the large samples

Continuous or composite representative samples are generally required for investigation of soil deposits or rock ledges considered for use as construction materials. Composite representative samples should represent the stratum or deposit to be used They are obtained by preserving all the material excavated between the appropriate depths in a bore hole or from a narrow channel in the walls of a test pit, or they may be prepared by mixing samples taken at various depths and from various bore holes and test pits. Both the individual samples and the final composite sample may, when too large, be reduced in size by mixing and quartering in either the field or laboratory

The required size of composite samples varies greatly with both the composition of the material, its intended use, and the extent of the laboratory investigation. Only very approximate indications of the requirements can be given here, and whenever possible, the laboratory should be consulted before samples are taken.

When the soil is to be used in earth dams, fills and backfills, base courses for airfields and roads, or for asphalt aggregate, a sample weighing about 500 lb will usually be adequate for a standard series of tests This amount must be increased when several series of tests are to be performed, or when a part of the material may be discarded as unsuitable for the actual tests. On the other hand, a

much smaller amount may be sufficient when only specific tests are to be performed When the final sample is prepared by mixing composite samples from various levels or bore holes, the individual composite samples should weigh from 100 to 200 lb

In the Standards of 1946 by the American Society of Testing Materials, it is specified in Designation D75-46T that for preliminary investigation of a source of supply, samples of pit run gravel and sand for use as highway materials should not be less than 100 lb in total weight and so large that each sample will contain not less than 25 lb of sand and/or 50 lb of gravel For example, a 200-lb sample should be taken when the deposit contains only 25 per cent gravel

In Bulletin 27 (Revised), Concrete Analyses Testing and Research, Waterways Experiment Station, Vicksburg, Miss , July 1947, it is specified that the total amount of unprocessed aggregate from gravel pits and rock ledges, submitted for analysis and concrete mixture design, should not be less than the following amounts

Size of coarse aggregate in concrete, in	3/4	1-1/2	3	6
Size of total sample, lb	1000	1500	2000	3000

When the aggregate is to be prepared by crushing of rock cores, the diameter of the core should not be less than 6 in and the length not less than 8 ft for each ledge investigated, and the diameter should be increased to at least 10 in. when 6-in aggregate is to be prepared.

The requirements for undisturbed samples of soil and the influence of unavoidable disturbances are discussed in greater detail in Chapter 6, and the requirements for samples of water in Section 3 10

CHAPTER 2
METHODS OF SUBSURFACE EXPLORATION

2.1 General

The purpose of this chapter is to present a brief outline of the various methods of exploration in such a manner that it will serve as a background for sampling operations, the main subject of the report Only general principles and not details of the various methods of exploration are described, and greater stress is laid on a discussion of their advantages and disadvantages, the accuracy with which changes in the character of the material can be determined, and features which may affect sampling operations and the quality of the samples obtained A general classification and summary of the principal features of the various methods of subsurface exploration is shown in Table 3 The methods will be described in the order shown in this summary, progressing from indirect through semi-direct to direct methods of exploration

2.2 Geophysical Methods -- General

Geophysical methods of exploration consist in identifying changes in the character of subsurface materials by measuring changes in certain physical characteristics of the earth at or near its surface The major geophysical methods involve measurement of surface anomalies in the gravitational, magnetic, and electric fields of the earth and measurement of changes in electrical resistance and rate of propagation of elastic waves in the earth. They are classified as gravitational, magnetic, electrical, and seismic methods

These methods have been developed primarily for and are used extensively in prospecting for oil and minerals, but some electrical and seismic methods are also being used on an increasing scale in subsurface explorations for civil engineering purposes. In addition, a special method has been developed for use in the latter field It is basically a seismic method but it differs from other seismic methods in so many respects that it may be placed in a separate category and called the continuous vibration method. Several minor geophysical methods, utilizing radioactive, thermal, and other properties of subsurface materials, are used to a limited extent and under special conditions. For a detailed description of the theory and practice of geophysical methods of exploration see references 211, 214, 221, 227 and the publications listed in Section 4 of the classified bibliography.

TABLE 3 - METHODS OF SUBSURFACE EXPLORATION

GROUP	TYPE	METHOD		MEASUREMENTS OR METHODS OF ADVANCE	INDICATION OF CHANGE IN MATERIAL	TYPE OF FORMATION	USE IN CIVIL ENGINEERING
INDIRECT METHODS	Geophysical Methods (1)	Gravitational	Gravimeter Pend	Intensity of gravitational field	Anomalies grav field No depth control	Rock ridges domes intrusions faults steeply inclined strata	Not used in Civil Engineering
			Torsion Balance	Curvature of gravitational field			
		Magnetic Methods		Intensity of magnetic field supplemented by inclination declination	Anomalies magn field Limited depth control	Ore bodies faults ridges and intrusions igneous mag rocks	Reconnais rock ridges faults rapid econ application limited
		Electrical (Galvanic)	Resistivity	Current and potential drop	Variat in resistivity	Rock soils and ground water horizontal and inclined strata at shallow to medium depths	Reconn general stratigraphy detection of irregularities Rapid fairly reliable with correlation borings incl represent samples
			Pot Drop Ratio	Ratio pot drop betw three points	Variat pot drop ratio		
		Seismic	Refraction	Travel times of refracted waves	Veloc compres waves		
			Reflection	Travel times of reflected waves	Veloc compres waves	Deposits at depths over 2000 ft	Not used in Civil Engineering
		Continuous Vibration		Contin waves variable frequency phase amplitude power settlement	Variat velocity amplitude etc of shear waves	Soil and rock shallow depths horizontal and inclined strata	Reconn. general stratigraphy dynamic properties in development
	Probing or Sounding	Rod alone	Simple Point	Driving by drop hammer	Blows penetration	All soils without large stones	Reconn rock and rough soil profiles rapid not always reliable
			Screw Point	Static pressure and rotation	Rev s penetration	Medium to hard cohesive soils	
			Cone or Disk	Static pressure constant speed	Force penetration	Soft to stiff and dense soils	Shallow reconn and control tests
		Rod with a Sleeve Pipe	Wash Point	Alternating jetting and jacking	Variations in point resistance alone	Primarily cohesionless soils	Compactness profiles sand silt
			Large Cone Point	Alternating jacking and driving of rod and sleeve pipe In some cases concurrent jacking of rod and sleeve		Soft to hard and dense soils without stones and boulders	Reconnaissance detection irregularities detail stratigraphy but without positive identification correlate with borings Fast inexpensive indication of compactness strength bearing capacity
			Flush Cone Point		Variat point resistance and skin friction		
			Cone and Collar				
		Kjellman Insitu Method		Insertion and withdrawal of resistor	Withdrawal resistance	Primarily soft and loose soils	
SEMI-DIRECT METHODS	Borings	Displacement Boring	Slit Cup Sampler	Driving closed sampler into the soil rotation release of piston sampling	Blows or static force versus penetration	Loose to medium cohesionless soils soft to stiff cohesive soils	Reconn and detailed exploration Rapid under favorable conditions
			Piston Samplers				
		Wash Boring (3)		Light chopping strong jetting removal of cuttings by circulating water	Cuttings in water rate of progress (2)	Soft to stiff cohesive and fine to coarse cohesionless soils	Reconn to special explorations ground water inexpensive equip
		Percussion Drilling -- also called Cable-Tool Drilling		Power chopping periodic removal of slurry with bailers or sandpumps	Cuttings in slurry rate of progress (2)	Soil and rock but difficult in soft sticky clay or loose sand	Penetrat gravel boulders rock supplementing wash auger borings
		Rotary Drilling		Power rotation of bit cuttings removed by circulating drilling fluid	Cuttings in fluid rate of progress (2)	Soil and rock except stony or very porous soil fissured rock	Detailed and special exploration fast water observations difficult
DIRECT METHODS		Auger Boring		Hand or power operat with periodic withdrawal or use of contin auger	Soil removed constitutes representative sample	Medium to stiff cohesive soils Part saturated sand and silt	Shallow reconn or detail explor Power operat fast special expl
		Continuous Sampling		Alternating sampling and cleaning with drive samplers or core barrels	Samples obtained are represent or undisturb	All soils and rock - cohesionless soils may require freezing	Best method for detail soil expl Majority of explorations in rock
	Accessible Explorations	Test Pits and Trenches Caissons Drifts Tunnels		Excavation by hand and power tools use of explosives sheeting of walls	Inspection mapping sampling and testing material in situ	Soil and rock unstable soils require ground water control compressed air or freezing	Detailed and special exploration Expensive but best of all methods except when load reduct on causes soil displacement and disturbance
		Accessible Borings		Power operated disk or bucket augers single tube core barrels mucking			

(1) Only principal methods listed (2) Samples of cuttings settled from wash water slurry or drilling fluid are called Wet Samples They are non-representative and inadequate for positive identification of soil strata however the borings make separate sampling operations possible (3) Wash borings with representative samples taken each stratum often called Dry Sample Borings"

Gravitational methods are based on differences in density of subsurface materials. They consist in determining either the vertical intensity (by pendulum or gravimeter) or the curvature and gradients (by torsion balance) of the gravitational field at various points of the area under investigation. Any anomalies existing after correction has been made for terrain, planetary, and other effects indicate changes in the density of the subsurface materials. These methods are particularly valuable in tracing the boundaries of steeply-inclined subsurface irregularities, such as faults, intrusions, domes, and ridges The methods are not suited for depth determinations to fairly horizontal strata and are rarely used in subsurface explorations for civil engineering purposes

The magnetic method is based on differences in the magnetic properties of subsurface materials The vertical intensity and occasionally also the inclination and the horizontal intensity and declination are measured at various points and corrected for normal variations in the magnetic field and other effects The interpretation of the remaining magnetic anomalies yields primarily qualitative results, although quantitative results, such as depth determinations, can be obtained under special conditions The method cannot yield the detailed information obtainable by other methods, but it is the simplest and quickest of all geophysical methods, and is used extensively as a reconnaissance method in searches for oil and minerals It has also been used successfully in the general exploration of dam sites underlain with igneous or crystalline rocks, which often are strongly magnetic compared to sedimentary deposits

The general principles and special features of electrical, seismic, and dynamic vibration methods are discussed in the following three sections, but their common advantages and limitations and fields of application are summarized here

In comparison with borings, large areas or projects of great linear extent can be explored more rapidly and economically by geophysical methods. These methods have the further advantage that they indicate average conditions within a limited area and not along a single vertical or inclined line This facilitates detection of subsurface irregularities which often are missed by borings. The results obtained are generally satisfactory when only the depth to rock or the location of subsurface irregularities or deposits materially different from the surface soil is desired. The general character of subsurface materials can often be estimated, but the materials cannot be definitely identified by geophysical methods alone, these methods should therefore always be supplemented by borings in which representative or undisturbed samples are obtained

Geophysical methods are especially well suited for reconnaissance exploration of large areas to be used for dams and reservoirs, tunnels, highways, airfields, and large groups of buildings. They have also been used successfully for location of gravel deposits and other construction materials. The presence of and depth to ground water can be determined under favorable conditions, but the influence of the water may be obscured by the character and sequence of strata adjacent to the water table and by varying contents of mineral salts dissolved in the water.

2.3 Electrical Methods

The majority of electrical methods of exploration are based on differences in electrical conductivity or resistivity of the subsurface materials. The resistivity of dense, igneous rocks is much larger than that of loose, saturated sediments, however, dry sedimentary deposits may have a fairly large resistivity. In general, resistivity depends mainly on the quantity and salinity of the water in the pores and less on the mineral constituents of ordinary soils and rocks Evaluation of field results obtained by electrical methods of exploration is therefore based more on the relative than on the actual values of the resistivity A great variety of electrical methods of exploration has been developed, but only two, the potential-drop-ratio or PDR method and especially the resistivity method, are used to any extent in explorations for civil engineering purposes

The resistivity method (412 to 415, 419 to 422, 431, 432) consists in producing an electrical field in the ground by means of two current electrodes, Fig 2 By measuring this current and the potential drop between two intermediate or potential electrodes, the apparent resistivity of the soil to a depth approximately equal to the spacing, a, of the electrodes can be computed The resistivity unit is often so designed that the apparent resistivity can be read directly on the potentiometer. In "resistivity mapping" or "transverse profiling" the electrodes are moved from place to place without changing their spacing, and the apparent resistivity and any anomalies within a depth equal to the spacing of the electrodes can thereby be determined for a number of points. In "resistivity sounding" or "depth profiling" the center point of the set-up is stationary whereas the spacing of the electrodes is varied A detailed evaluation of the results of resistivity sounding is rather complicated, but preliminary indications of subsurface conditions may be obtained by plotting the apparent resistivity as a function of the electrode spacing The resultant diagram will generally show a more or less pronounced break or change in curvature when the electrode spacing reaches a value equal to the depth to a deposit with a resistivity materially different from that of the overlying strata

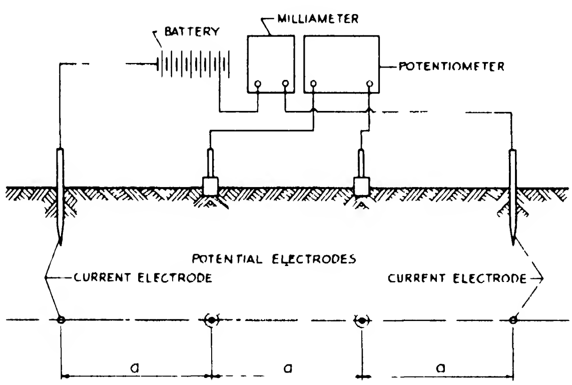

FIG 2 - ELECTRICAL RESISTIVITY METHOD

In the potential-drop-ratio method (214, 427) the two current electrodes are placed very far apart, 5 to 10 times the desired effective depth penetration of the survey, and the measurements are carried out in the vicinity of one of the current electrodes, Fig 3 Three equidistant potential electrodes are used and placed in lines through the current electrode Only the potential drop, or rather the ratio between the potential drops A-B and B-C, is measured The center distance, R, is

varied, whereas the electrode spacing, b, is kept constant or is a definite fraction, generally 1/3, of R The observed potential-drop-ratios are first multiplied by a correction factor, which depends on the relative values of b and R, and are then plotted as a function of R. A break or change in curvature of the diagram obtained indicates strata with a resistivity different from that of the surface soil The ratio between the corresponding value of R and the depth to the stratum varies between 1 5 and 3 5 according to the electrode spacing and the conductivity of the various strata

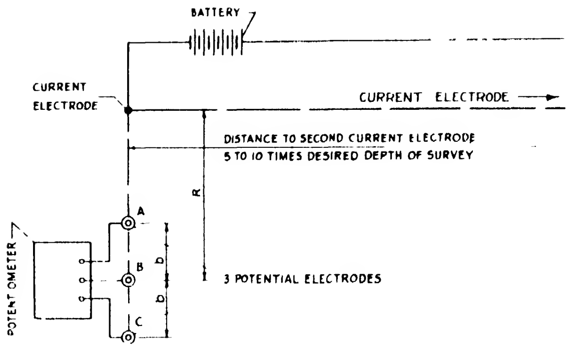

FIG 3 - POTENTIAL DROP RATIO METHOD

The principal measurements are usually carried out along a line at right angle to the line between the two current electrodes, but profiles radiating from one of the current electrodes are used for determination of the dip and strike of the subsurface strata In other PDR methods the base length is relatively small, and the three potential electrodes are placed between the current electrodes and with a spacing which is a function of the base length

The potential-drop-ratio method gives sharper indications of vertical or steeply-inclined boundaries and, under certain conditions, more accurate depth determinations than the resistivity method However, it is more susceptible to surface interference and to small irregularities in the surface soil The resistivity method is generally preferred in explorations for civil engineering purposes Both methods have been used extensively in obtaining rock-line and preliminary rough soil profiles for large projects and in prospecting for gravel deposits and other construction materials

2.4 Seismic Methods

Seismic methods are based on the fact that the velocity of propagation of a wave or impulse in an elastic body is a function of the modulus of elasticity, the Poisson ratio, and the density of the material, and that very great differences exist between wave velocities in solid rock and in loose, sedimentary deposits. An impulse will produce longitudinal or compression waves, transverse or shear waves, and various types of surface waves. It is primarily the velocity of longitudinal or compression waves which is utilized in the seismic methods of exploration The range of velocities for such waves is indicated in Fig 4

The elastic impulse is produced by exploding a small charge of high velocity dynamite placed in a shallow bore hole. The time required for the impulse to travel from the shot point to various points on the ground surface is determined by means

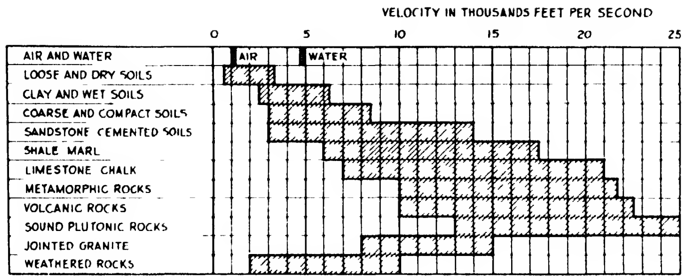

DIAGRAM DRAWN FROM DATA BY FAHLQUI T (320) HEILAND (213) PEELE (~31) SHEPHARD (425)

FIG 4 - VELOCITY OF LONGITUDINAL OR COMPRESSION WAVES

of small vibration detectors or "geophones" which transform the vibrations into electrical currents and transmit them to a recording unit or oscillograph, equipped with a timing mechanism There are two principal types of seismic methods of exploration, one which depends on the refraction of the elastic waves between the various strata, and one which utilizes the reflection of the waves at the interfaces between the strata

The refraction method of seismic exploration (420 to 426) is based on the fact that an elastic wave in travelling across a boundary between materials is refracted toward the plane of the boundary when it enters a material which transmits the wave with a higher velocity and toward the perpendicular to the boundary when it passes from one material to another with a lower velocity of wave propagation The detectors are placed at various distances from, but generally along a straight line through, the shot point, Fig 5. In actual practice several shots are fired successively at various distances from each set-up of three to four detectors. The distance from the last shot to the farthest detector, or the maximum shooting distance, must be from three to twelve times the desired depth of penetration

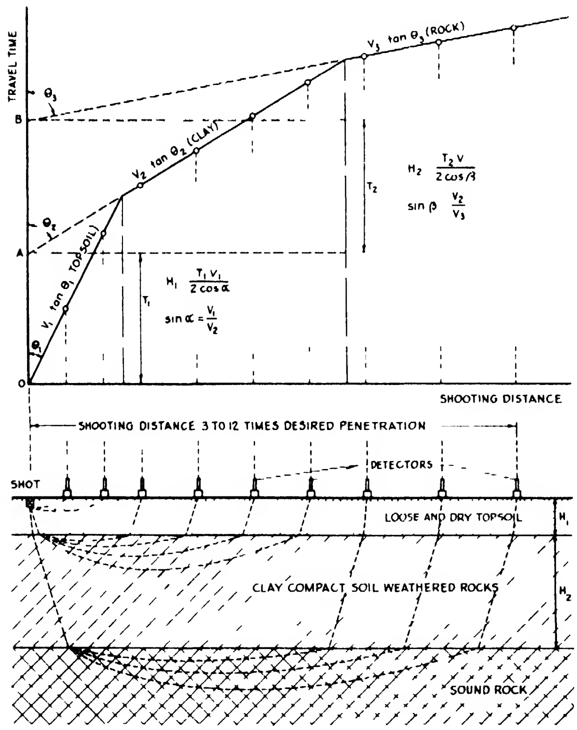

FIG 5 - SHALLOW SEISMIC REFRACTION SURVEY

Only the arrival time of the initial impulse at each geophone is utilized. If the successively deeper strata transmit the waves with increasingly greater velocities, the paths traveled by the first impulses will be similar to those shown in Fig. 5. Those recorded by the nearest detectors pass entirely through the overburden, whereas those first reaching the

farther detectors travel downward through the lower-velocity material, horizontally within the higher-velocity stratum, and return to the surface as shown By plotting the travel times as a function of the distances between the geophones and shot points, Fig 5, a curve is obtained which indicates the wave velocity in each stratum and which may be used to determine the depths to the boundaries between the strata

It should be noted that the seismic refraction method can be used only when the wave velocity is greater in each successively deeper stratum The presence and thickness of a stratum which transmits the waves at a lower velocity than the overlying stratum cannot be determined by this method Complications are occasionally encountered when the wave velocity in the overburden or loose deposits increases gradually with depth The path of the first impulses and the travel-time diagrams will then be curved, and it may be difficult to determine the actual wave velocities and the thickness of the non-uniform strata When inclined strata are encountered, only the average depths can be determined by a single travel-time diagram, and it is necessary to reverse the positions of the shots and detectors and shoot "up-dip" and "down-dip" in order to determine the actual depths and the dip of the strata along the shot line The strike and maximum dip of the strata are determined by comparing parallel profiles or by taking profiles along two or three intersecting lines

Several variants of the basic refraction method have been developed. By special arrangements of the shot points, detectors, and shooting lines, and by special methods of evaluating the data obtained, it is often possible to decrease the required shooting distance and the number of shot points, and to obtain increased accuracy in determining the depth to subsurface strata below specific points instead of average depths

The reflection method of seismic exploration utilizes impulses reflected from the boundaries between deep strata, Fig. 6. This method requires a shooting distance of only one-tenth to one-half of the depth of penetration and smaller explosive charges than the refraction method However, the reflected impulses are weak and easily obscured by the direct surface and shallow refraction impulses, and arrangement to screen out the latter impulses has not yet been fully successful. The reflection method is therefore used to determine the depths to deep strata so that the reflected impulses

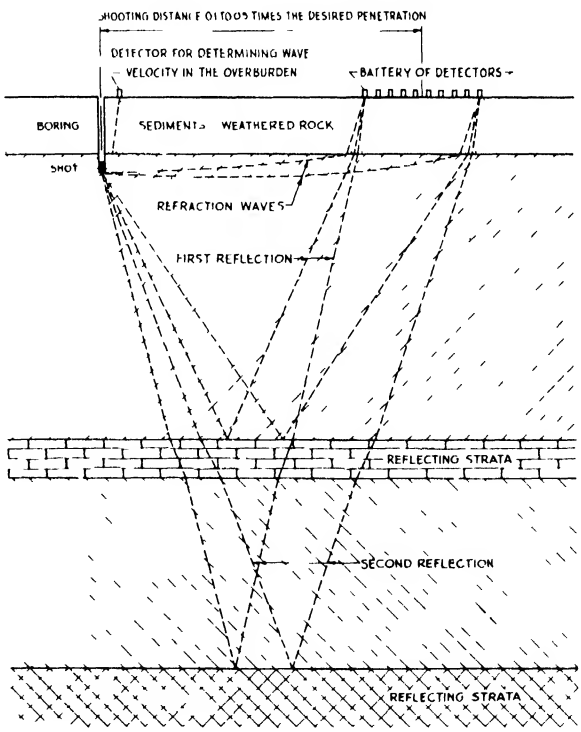

FIG 6 - DEEP SEISMIC REFLECTION SURVEY

will arrive at the geophones after the stronger surface and shallow reflected impulses have been dissipated. The minimum depth of penetration, at which reliable results can be obtained by the reflection method, is about 2000 ft The method is therefore not applicable to the relatively shallow explorations for civil engineering purposes.

The refraction method of seismic exploration is well suited for determination of the depth to rock and other strata substantially different from the surface materials. For this purpose it is now used to a greater extent than the electrical methods, because it is less influenced by surface irregularities and structures, and it also has the advantage that it can be used on water-covered areas Nevertheless, the electrical and seismic methods are in several respects complementary, when definite results cannot be obtained with one of these methods, the other one can often be used successfully

2.5 Continuous Vibration Method

Seismic methods of subsurface exploration utilize longitudinal or compression waves, produced by a single elastic impulse As indicated, these methods may be used for determination of the depth to rock or to strata in which the wave velocity is materially greater than in the overlying strata, but they furnish only limited information on the physical properties of the materials Additional information on these properties can be obtained by the continuous vibration method, which was developed by the engineers of the **Deutsche Gesellschaft fur Bodenkunde** (**Degebo**) and the **Geophysical Institute of Gottingen,** see references 407 to 410, and 416 Brief descriptions of the method are also given by **Brennecke and Lohmeyer** (206), **Heiland** (214), **Loos** (229), **and Terzaghi** (245).

The continuous vibration method utilizes continuous transverse or shear waves -- probably Love waves -- of controllable amplitude and frequency. These waves are produced by a mechanical vibrator, which in principle consists of a pair of counter-rotating disks on parallel shafts. The disks are eccentrically weighted or mounted in such a manner that the centrifugal forces thereby produced cancel each other in one direction and produce a sinusoidal variable force in a direction perpendicular thereto. The vibrator is generally used in such a position that the two parallel shafts with the disks are in a horizontal plane, and sinusoidal vertical forces are then produced, Fig 7A, but horizontal forces can be produced by up-ending the vibrator so that the two shafts then are located in a vertical plane. Pure moments in either a horizontal or vertical plane can be

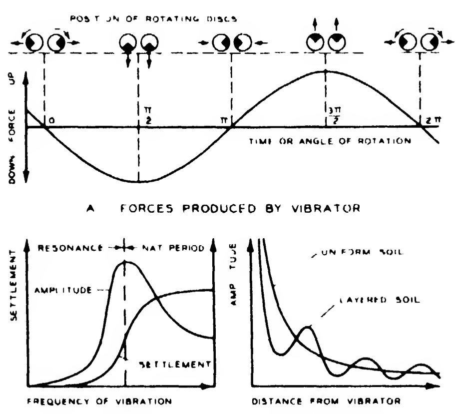

FIG 7 - CONTINUOUS VIBRATION METHOD

produced by using two pairs of disks with the eccentricity of one pair 180 degrees out of phase The vibrator used by "Degebo" has a base area of about 10 sq ft and weighs from 4500 to 6000 lb The frequency can be varied from 5 to 60 cycles per second For a given frequency the impulse or amplitude can be varied by changing the eccentric weights or the eccentricity of these weights or the disks The dead weight of the vibrator can be changed by means of removable weights

The waves imparted to the soil are picked up and recorded by seismic detectors, which are placed at various distances from the vibrator, usually with one detector on the vibrator itself Tests are performed at various frequencies and with various loads on the vibrator The observations include (1) the phase shift at the various detectors, (2) the amplitude as a function of frequency and distance, (3) settlement of the vibrator as a function of the frequency and the load on the vibrator, and (4) the power input as a function of the frequency

The travel times of the waves to the various detectors can be computed from the phase shifts When they are plotted as a function of the distance, the depths to or thickness of the strata may be determined as shown in Fig 5 for a shallow seismic refraction survey However, the computations are often complicated by changes in wave velocity due to dispersion at certain combinations of frequencies and depths to the boundaries of the substrata

The amplitude plotted as a function of the frequency will show a distinct maximum at the resonance frequency or natural period of vibration of the ground, Fig 7B. The settlement and power input vary with the frequency, increasing toward and with the maximum gradient at resonance The settlement curve shown in Fig. 7B indicates the accumulated settlement obtained by gradually increasing the frequency The power transmitted to the soil is the difference between the actual power input and the power consumed at no load or balanced rotating disks This difference, plotted as a function of the frequency, reaches a maximum value at the resonant frequency of the system The natural period of vibration of the ground can thus be determined in several ways with reasonable accuracy Knowledge of the natural period of vibration is very important in the design of foundations for machines or structures subject to induced vibrations

The amplitudes permit an estimate of the coefficient of dynamic subgrade reaction, and the decrease of amplitude with distance indicates the damping effect of the soil These two physical properties as well as the velocity of the waves and the natural period of vibration give some indication of the soil type In homogeneous soil the amplitude decreases rapidly but uniformly with the distance from the vibrator, Fig. 7C, but in layered soil the refracted or reflected waves cause interference with the directly transmitted waves In the latter case the amplitude-distance curve will show distinct maxima and minima, the spacing of which depends on the depth to the substrata. This spacing is constant when the layers are parallel to the ground surface, but it increases or decreases with distance in case of inclined strata.

By combining the continuous vibration method with the seismic refraction

method, the velocities of both the compression waves and the slower shear waves can be determined. These velocities can be expressed by two independent equations, involving the modulus of elasticity, the Poisson ratio, and the density of the material. When the velocities are determined and one of the above mentioned physical coefficients is known or estimated, the other two coefficients can be computed

Based on empirical correlations of collected data, tables have been prepared which give directly the allowable bearing capacity of the soil as a function of either the velocity of the shear waves or the natural period of vibration, **Brennecke and Lohmeyer (206), Loos (229) and Terzaghi (245).** Such tables should, of course, be used only with great caution, especially in case of exploration outside the region for which the correlations have been made It should also be noted that whereas the continuous vibration method can give some indication of the density and prospective compaction of cohesionless or partially saturated materials, it cannot furnish any information on the consolidation characteristics of saturated cohesive soils

As will be seen from this brief review, it is theoretically possible to obtain considerable information on both the soil profile and certain physical properties of the soil by means of the continuous vibration method However, conditions are often considerably more complicated than outlined above, and with exception of the natural period of vibration, it is not always possible to determine these physical properties and the soil profile with satisfactory accuracy The depth of penetration of the continuous vibration method is reported to be about 40 m under favorable conditions, but the practical limit of this depth has not yet been reliably established, and it is, in any case, small compared to that of the seismic refraction method The continuous vibration method has been used to a considerable extent in Germany, but so far only in a few cases in this country The method must be considered as still in the stage of development, but it has interesting possibilities.

2.6 Sounding Methods -- General

Soil sounding or probing consists in forcing a rod, a rod encased in a sleeve pipe, or a wire and resistor body into the soil and observing the penetration or withdrawal resistance Variations in this resistance indicate dissimilar soil layers, and the numerical values of the resistance permit an estimate of some of the physical properties of the strata Soil sounding can therefore be considered as a method of both exploration and field testing Similar data can also be obtained by observation of the penetration resistance of a drive sampler, discussed in Section 4.10.

Recent advances in design and operation of soil sounding apparatus and in methods of evaluating the results obtained have increased the use of sounding. The development and principal types of soil sounding equipment will be described in the following three sections, but space limitations permit only reference to the various theories and empirical correlations which have been advanced for interpretation of the data obtained The advantages and limitations of soil sounding methods may be

summarized as follows·

When the soundings are properly performed with recently improved equipment, the sounding profiles obtained will generally furnish consistent data on the depths to different soil strata, but very misleading results can also be obtained by some of the sounding methods and when the soil contains stones and boulders

Continuous sounding profiles may indicate the presence of thin strata which often remain unobserved in boring operations, but the strata encountered cannot be definitely identified by soundings alone Soil soundings should therefore be supplemented by borings unless the soil types found in the area under investigation already are known

Soundings are generally considerably faster and cheaper than borings In case of erratic soil conditions, it may be advantageous to replace some of the borings with a greater number of soundings and thereby obtain more complete data on variations in the soil profile

Sounding profiles give indications of the consistency of cohesive soils and the compactness of cohesionless soils in situ This information is very valuable when undisturbed samples are difficult and too expensive to obtain, as in saturated cohesionless soils

In regions where sufficient correlations of soundings with borings, laboratory tests on prevalent soil types, and field loading tests or the behavior of completed structures have been made, and where soil conditions are favorable for the use of sounding methods, it has been possible on the basis of soundings alone to estimate the approximate bearing capacity of soil strata, the length and bearing capacity of piles, and in case of some foundations on cohesionless soils, even the approximate settlements of the proposed structure However, it should be noted that sounding profiles do not give information on the permeability of the soil or the consolidation characteristics of relatively impermeable cohesive soils.

Correct interpretation of sounding profiles requires considerable experience, especially when estimates of bearing capacity and settlements are attempted. Very misleading results can be obtained by inexpert execution of the work and interpretation of the data Great caution should be exercised in applying the results of correlations outside the region or area for which the correlations were made.

In general, small and large areas can be explored rapidly and economically by soil sounding methods, especially when the depth of exploration is moderate and the soils penetrated are soft or loose. Soundings furnish data which in several respects supplement those obtained by borings, but soundings alone cannot provide sufficient data for the final design of important or unusual foundation and earth structures, and in any case, not when consolidation, seepage, and earth or groundwater pressures must be taken into consideration.

2.7 Simple Sounding Rods

Dynamic resistance.- The oldest and simplest form of soil sounding consists in driving a rod into the ground by repeated blows of a hammer, Fig 8 and 9 The penetration of the rod for a given number of blows with a hammer of constant weight and drop, or the number of blows required per foot penetration of the rod, may be used as an index of the penetration resistance and correlated directly with local foundation experience (219, 225, 319) However, the numerical value of this index depends not only on the character of the soil but also on the diameter, length, and weight of the rod in relation to the weight and drop of the hammer, and more reliable results are obtained when the index is translated into the dynamic force resisting penetration or into a pressure per unit area of the rod by means of formulas similar to the pile driving formulas (225, 351, 931)

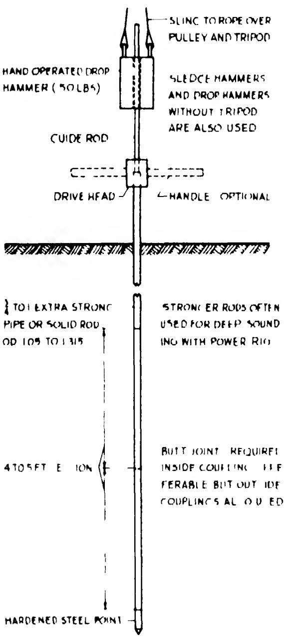

FIG 8 SIMPLE LIGHT SOUNDING ROD

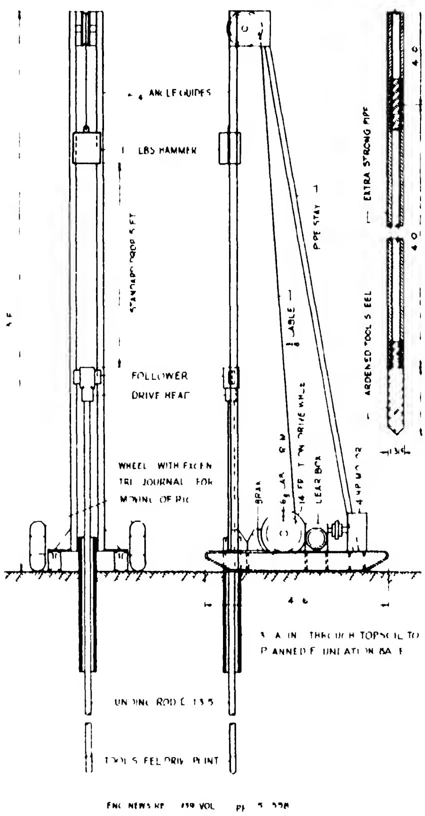

FIG 9 OHIO PORTABLE RIG FOR ROD SOUNDING

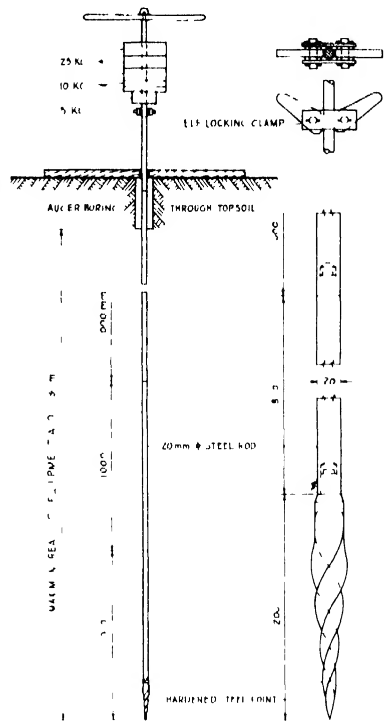

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FIG 11 ROTATED SOUNDING ROD WITH STATIC LOAD

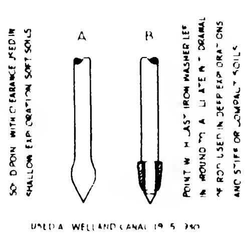


FIG 10 ROD POINTS WITH CLEARANCE

Since the skin friction acting on the rod is cumulative with depth, the penetration resistance does not directly represent the strength or density of the strata encountered In recent years the skin friction is often determined at short intervals of penetration by the resistance to withdrawal and/or rotation of the rod, and separate diagrams for the point resistance and accumulated skin friction can thereby be obtained However, the dynamic friction during driving may not always be equal to the static friction during withdrawal or rotation The approximate point

resistance may in some cases be determined directly by use of an oversize drive point, Fig 10, but the method is not reliable when the depth is great and when the soil is soft or loose and saturated A great reduction in withdrawal resistance can generally be obtained by use of a clearance sleeve, Fig 10B, which is left in the ground upon withdrawal of the rod

Penetration by rotation.- In 1917 the Geotechnical Committee of the Swedish State Railroads (967) -- see also 332 and 353 -- introduced a sounding rod which is forced into the soil in part by a static load and in part by rotation of the rod, Fig. 11. This method is used extensively in the Scandinavian countries, and the following description is based on minor modifications introduced by the Danish State Railroads, see **Godskesen (323, 324, 206, and 615).** The rod is provided with a screw point with a diameter about 50 per cent greater than that of the rod The penetration is first recorded for successive static loads of 5, 15, 25, 75, and 100 kg The rod with the final static load of 100 kg is then rotated, and the penetration is observed for each 25 half turns A diagram of the variations of this penetration with depth is then compared with similar diagrams obtained in the same region and under conditions for which the bearing capacity of the soil strata or the required length and bearing capacity of piles have been determined by other means

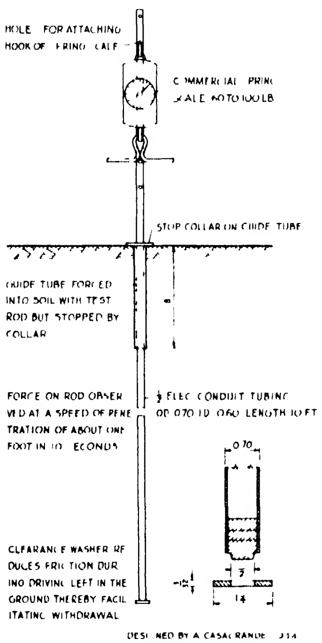
According to **Godskesen (323, 324),** fair foundation conditions, suitable for spread footings, exist when the penetration is less than 50 cm for each 25 half turns, and end-bearing piles can be used when the penetration is less than 5 to 10 cm However, these rules should not be applied indiscriminately, and the general character of the soils in the region, the depth to the strata under consideration, and the possibility that skin friction may be active and decrease penetration in spite of the oversize drive point must be taken into consideration The method is relatively fast and inexpensive, even when compared with other sounding methods, but it is not suited for exploration of coarse and gravelly soils or very compact or hard soils. Neither does the method furnish adequate details on the soil profile when soils are so soft that they are penetrated by the sounding rod without rotating it but simply by placing the above mentioned static loads on the self-locking clamp

Static resistance.- Variations in static penetration resistance of a sounding rod, which is pushed or jacked slowly into the soil, can be determined with greater accuracy than variations in dynamic resistance The numerical values of the static resistance are also easier to correlate with the strength and bearing capacity of the soil. Static rather than dynamic penetration resistance is therefore measured in the majority of the recently developed soil sounding methods, especially when these methods are used in exploration of relatively soft soil deposits

The test rod shown in Fig. 12 was developed by **A. Casagrande** for detection of soft spots in shallow hydraulic fills covering large areas. The washer at the bottom of the rod provides outside clearance and is left in the ground, thereby facilitating withdrawal of the rod. The penetration resistance is measured by a simple commercial spring scale. For each type of fill this resistance is correlated with

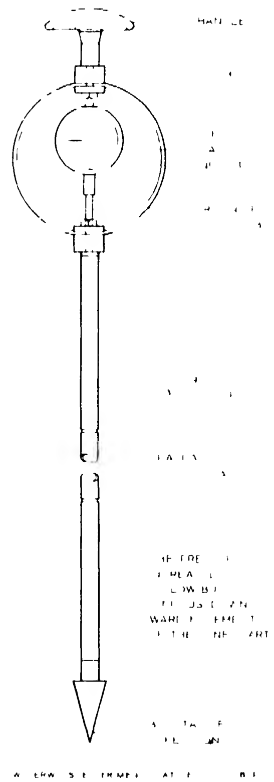
the water content and degree of compaction of the soil, as determined by laboratory tests on samples obtained in borings or test pits For example, it was found that a fill of silty clay was satisfactory when the penetration resistance exceeded 40 lb, whereas a resistance of 20 lb or less indicated soft or loose materials which should be replaced.

A cone penetrometer built and used by **Keith Boyd** for determination of the bearing capacity of subgrades for roads and airfields has been further developed by the Waterways Experiment Station in Vicksburg and is shown in Fig 13. It is used for shallow explorations in relatively soft deposits and determination of the capacity of such deposits to sustain various types of loads and traffic At depths at which



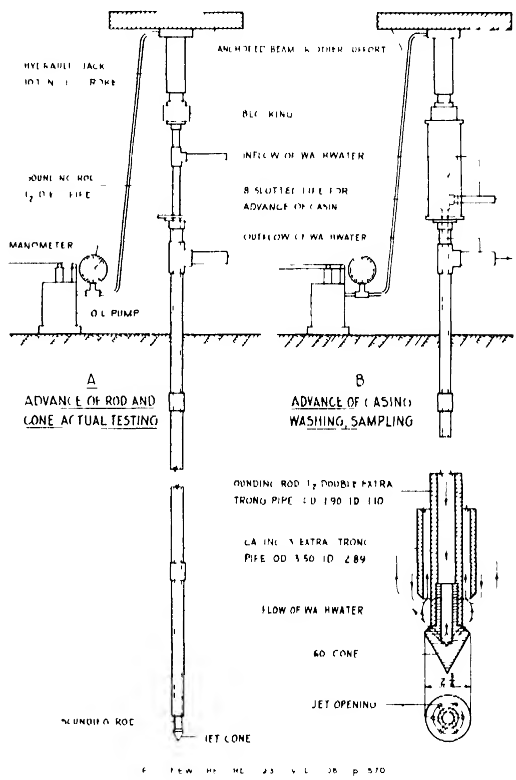
TEST ROD FOR SOFT FILLS

FIG 12



W E S PENETROMETER

FIG 13



TERZAGHI WASH POINT SOUNDING ROD

FIG 14

it is desired to determine the penetration resistance, the pressure on the handle is slowly increased until there is a perceptible but very slow and uniform downward movement of the cone The corresponding pressure is measured by means of the proving ring The small deformations of such a ring, compared to those of an ordinary spring dynamometer, greatly facilitate detection of a slow, downward movement of the cone

2.8 Encased Sounding Rods

Soft or cohesionless soils may close in on a sounding rod in spite of an

oversize drive point or washer The partial skin friction thereby established makes it very difficult to evaluate the results properly These difficulties are frequently encountered when soundings are extended to considerable depths The influence of skin friction in determining point resistance may be eliminated by encasing the sounding rod proper in a sleeve pipe Encased sounding rods were first developed by **Terzaghi (968) and Barentsen (601).** They may be designed and operated for (1) determination of point resistance alone, (2) additional determination of total skin friction on the sleeve pipe, or (3) determination of the specific skin friction exerted by the individual strata

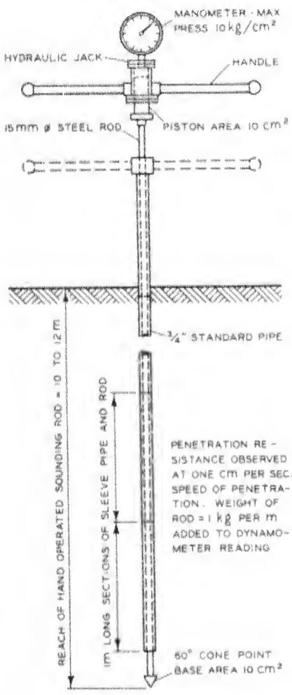
Point resistance.- When point resistance alone is to be determined, the skin friction on the sleeve pipe is usually decreased by means of jetting or use of an oversize cone point, thereby facilitating both the driving and withdrawal of the sounding assembly. Jetting is used in the method developed by **Terzaghi (246, 353, 968),** which also is called the Wash Point Method since the encased sounding rod is hollow and provided with a vented cone point to permit washing or jetting, Fig 14. The method is intended for exploration of sand deposits and determination of variations in density or compaction within the deposit A cycle of operations is as follows

The cone is jacked 10 in into the soil and the penetration or point resistance is measured by means of the manometer connected to the oil pump Water is then pumped through the rod and the vents in the cone point, flowing upward both inside and outside the sleeve pipe The upward flow of water causes temporary liquefaction of the sand immediately above the cone and removes some of this material through the sleeve pipe The water flowing from the pipe is collected in a bucket and samples are taken later from the settled material These samples are similar in character and value to the wash samples described under wash boring, Section 2 13 The sleeve pipe is then forced down until it touches the cone, the flow of water is stopped, and the entire operation is repeated The sand above the zone of temporary liquefaction will by arch and wedge action relieve the pressure on the sand below the cone The penetration resistance determined during the advance of the cone will therefore be more or less independent of depth below the ground surface and thereby indicative of the actual density of the soil

A light and simple, encased sounding rod, developed by **Barentsen (601),** is shown in Fig 15. It has been used extensively for exploration of soft surface deposits in Holland The penetration resistance is determined by pushing the cone into the soil at a speed of about 1 cm per sec and measuring the corresponding pressure by means of a hydraulic dynamometer The cross-sectional area of the piston in the dynamometer is equal to the base area of the cone, 10 cm^2, and the Bourdon gage therefore directly indicates the unit load on an area equal to that of the base of the cone After a 10- to 15-cm advance of the cone, the sleeve is pushed down until it touches the cone, and the entire assembly is then advanced until a new determination of the penetration resistance is to be made Such determinations are generally made for each 50-cm advance in depth. The sounding rod is operated by one or two men, and the maximum pressure is limited to 10 kg/cm^2 or a total

penetration resistance of 100 kg

Further development of sounding rods of the above mentioned type has been made by the Soil Mechanics Laboratory in Delft under direction of **T. K. Huizinga** (132, 218). The medium-size apparatus shown in Fig 16A has a manually-operated rack feed, whereby it becomes possible to exert greater pressure and to obtain a more uniform rate of penetration than with the Barentsen sounding rod The base area of the cone is 10 cm^2 and the maximum thrust 300 kg. A heavier sounding rig, Fig. 16B, is used for deep soundings and in dense or stiff soils The cone has a base area of 20 cm^2 and the jack a maximum capacity of 10 tons The lower end of the



P. BARENTSEN: PROC. INT. CONF. SOIL MECH. AND FOUNDATION ENG. VOL. 1, pp 7-10, HARVARD, 1936

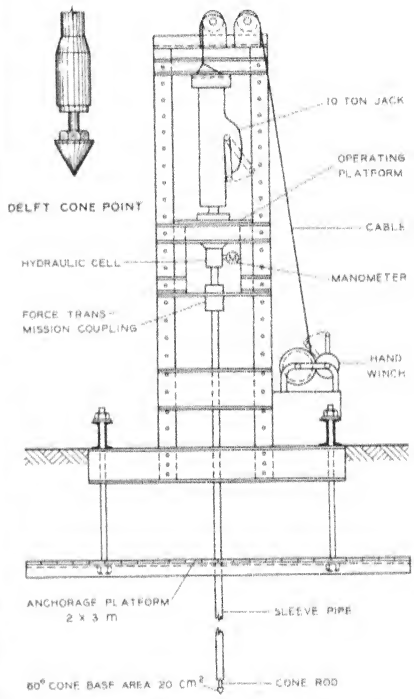
SOUNDING ROD WITH SLEEVE

FIG. 15

T. K. HUIZINGA GRONDMECHANICA - AMSTERDAM, 1942

DELFT SOUNDING ROD WITH RACK FEED

FIG. 16-A



T. K. HUIZINGA. GRONDMECHANICA - AMSTERDAM, 1942
E. E. DE BEER ANNALES DES TRAVAUX PUBLICS DE BELGIQUE - 1945

DELFT LARGE SOUNDING ROD

FIG. 16-B

sleeve pipe is reinforced with a short collar, but the outside diameter of this collar is still slightly smaller than the base diameter of the cone A bushing inside the sleeve pipe and a collar on the sounding rod proper limit the advance of the latter with respect to the pipe A special coupling permits transfer of the force from the jack to either the rod or the sleeve pipe A heavy steel frame with the jack and operating platform is attached to a base platform, which is placed in a 1-m deep hole and covered with soil to obtain necessary anchorage When used on water-covered areas, the sounding apparatus is operated from the adjustable mast shown in Fig 18.

Point resistance and total skin friction.- Determination of skin friction in addition to but separate from point resistance has the advantage that two complementary

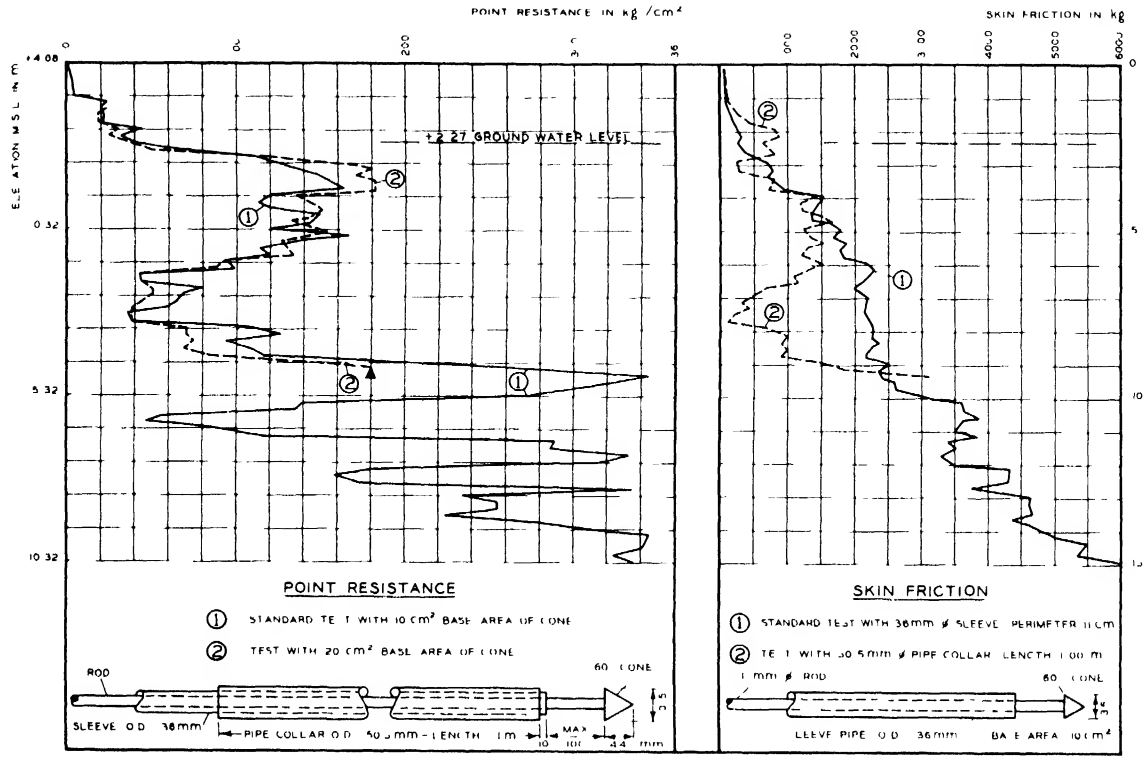
resistance diagrams are obtained and thereby additional data on the character of the soil and the bearing capacity of piles. When the sleeve pipe is given the same outside diameter as the base of the cone, the accumulated or total skin friction for the entire depth of penetration is determined by the force required to advance the sleeve pipe This method is widely used in Holland and Belgium although the specific skin friction is determined directly in some cases, see Fig 16

Both simple and encased sounding rods are used to a considerable extent in Switzerland The dynamic rather than the static method is generally preferred on account of the prevalence of coarse-grained and dense soil deposits. **Haefeli (931)** initiated the use of a simple sounding rod for snow surveys and adapted the method for soil sounding in cooperation with **Munger and Knecht.** The latter use a 1-1/4 in rod and a 140-lb hammer with 20-in drop, the skin friction is determined by rotation of the rod and other methods not specified, and the specific point resistance is computed in a similar manner as the point resistance of a pile An encased sounding rod is used by **Stump (350)**, who determines not only the driving resistance but also the resistance to rotation and withdrawal of the sleeve pipe Three different diagrams for the accumulated skin friction with depth are thereby obtained, and a more detailed estimate of variations in the skin friction is made possible The specific point resistance is determined by means of the Stern pile driving formula

Point resistance and specific skin friction.- The specific skin friction, or the skin friction exerted by the soil at a specific depth, can be determined as the rate of increase with depth from the diagram representing the total skin friction but not always with satisfactory accuracy Furthermore, the accumulated skin friction increases rapidly with depth and may reach such values that the relatively slender sleeve pipe cannot be driven to or withdrawn from the desired depth of exploration. These difficulties can be eliminated by providing the lower end of the sleeve pipe with a collar of limited length and the same outside diameter as the base of the cone, whereas the sleeve pipe proper has a smaller diameter.

Experiments by **De Beer (916)** indicated that both point resistance and skin friction, expressed as unit forces on the base area of the cone and the surface area of the collar, vary to some extent with the length of the collar when this length is small. **De Beer** suggests that the length of the collar should be about 100 cm when its outside diameter is 5 cm. Results of tests with two sounding rods are shown in Fig 16C. The diagrams of point resistance and skin friction marked (1) were obtained with a 10-cm^2 cone and a sleeve pipe with the same diameter and area, whereas the diagrams marked (2) were obtained with a 20-cm^2 cone and a sleeve pipe with a smaller diameter but provided with the 1-m long collar of the same diameter as the cone. It will be observed that the point resistance, expressed as a force on the unit base area of the cones, is nearly identical in the two cases Diagram (1) of the skin friction indicates the accumulated skin friction, and changes in the friction exerted by individual strata are discernible only as changes in slope of the diagram, whereas such changes are prominently displayed in diagram (2), which indicates the skin friction on the 1-m long collar. In case of deep soundings in soft or cohesionless

soils, there is a possibility that the soil may close in on the sleeve pipe, in spite of the clearance provided by the collar, and thereby interfere with accurate determination of skin friction on the collar



F. E. DE BEER, ANNALES DES TRAVAUX PUBLICS DE BELGIQUE, APRIL ... AUGUST 1945

DIAGRAMS OBTAINED WITH DE BEER SOUNDING ROD

FIG. 16 C

A recent improvement of sounding rods used in Holland and Belgium consists in connecting the top of the rod to the sleeve pipe by means of a coupling with a hydraulic or electrical dynamometer for measuring the point resistance The force from the jack is applied to this coupling and determined by another dynamometer The skin friction is the difference between the two forces measured or the distance between the two depth-force diagrams obtained With this arrangement it is possible to advance the cone and sleeve pipe concurrently and to obtain continuous diagrams for the point resistance and skin friction Furthermore, the cone is provided with a tapered sleeve which prevents reduction of the lateral pressure above the cone as well as entrance of soil into the space between the sleeve pipe and the rod and cone

Another method for determination of point resistance and specific skin friction has been developed by **Ostenfeld (957)**, but it should be classified as a field testing method rather than a method of exploration since the tests are performed in a 4-1/2-in. cased bore hole. The testing equipment consists of a pipe with 6 1-cm outside diameter, a flat piston with 4.8-cm diameter, and a piston rod It resembles a piston sampler but is not used for obtaining samples. After being seated on the

bottom of the bore hole, the piston is subjected to increasing loads, and a regular load settlement diagram is obtained. The pipe is then forced a given distance into the soil and its withdrawal resistance -- and thereby the skin friction -- determined, whereupon the bore hole and casing are advanced until a new test is to be performed.

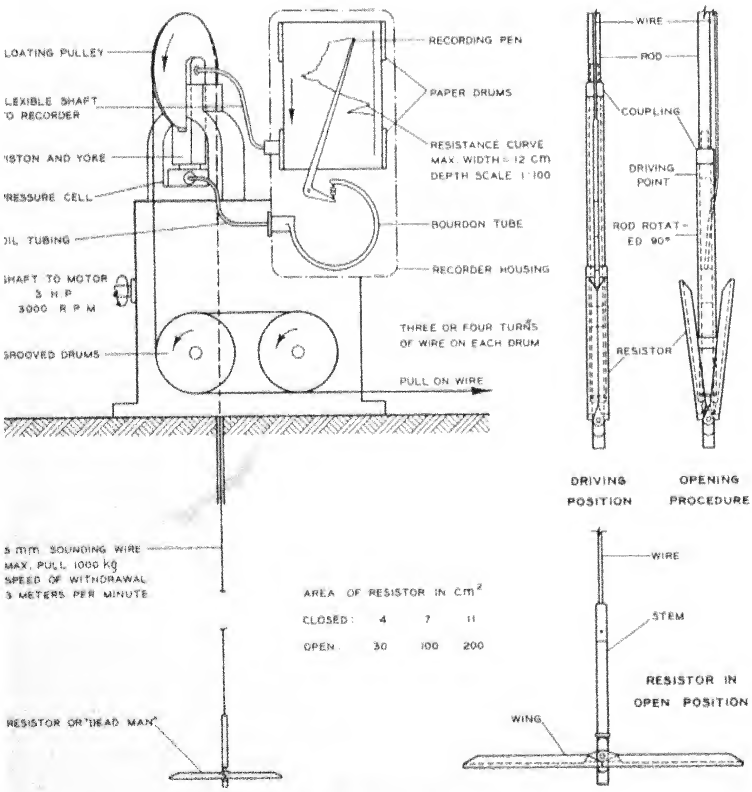
Evaluation.- As already indicated, determination of individual values of both point resistance and skin friction has the advantage that two diagrams are obtained which supplement each other and permit a more accurate estimate of the identity of the soil strata and their properties than can be obtained by determination of the point resistance alone.

The point resistance or the penetration resistance of the cone depends not only on the coefficient of internal friction and the cohesion of the soil but also on the stress conditions or the depth below ground surface. A theory covering the influence of these three factors on the cone penetration resistance has been advanced by **Buisman (207)** and is also described by **Barentsen (601), Huizinga (218), and De Beer (916).** Laboratory correlation tests are often made on selected samples from the general area under exploration and include cone penetration tests with various surface loads on the confined test specimen. These tests are furthermore supplemented by field observations of completed structures and general foundation experiences within the region. In this manner it has been possible to estimate the approximate values of the internal friction and cohesion as well as the compactness of soil strata and the bearing capacity for direct foundations and piles. Both the general theory -- see **De Beer (916), Huizinga (218), and Kollbrunner (225)** -- and field and laboratory correlations have also been extended to include estimates of the elastic properties of cohesionless soils and the settlement of structures founded on such soils. However, it should be noted that results of soundings cannot give information on consolidation characteristics of saturated cohesive soils.

2.9 Swedish Sounding Methods

An entirely new method of sounding has recently been developed by the Swedish Geotechnical Institute under direction of **W. Kjellman (147, 332, 940).** The principal part of the sounding apparatus, Fig. 17A, is a small resistor or "deadman" which is hinged in the center and attached to a wire rope. The resistor is folded and pushed down to the maximum sounding depth by means of a rod with an oval collar and a slot for the wire rope. The resistor is then opened by a 90° rotation of the rod and by pulling the resistor up against the rod collar by means of the wire rope, whereupon the rod is withdrawn. The actual sounding is now performed by withdrawing the resistor. The wire rope is attached to a small winch and a recorder which furnishes a diagram of the withdrawal resistance as a function of depth. The winch may be motor-operated as shown in Fig. 17A, but a smaller hand-operated model, which can be carried by one man, has also been developed. Since the diagram indicates the relative shearing resistance of soil strata in situ, it has been called the "Insitu Apparatus". The method is primarily suited for use in soft soils and has the advantages

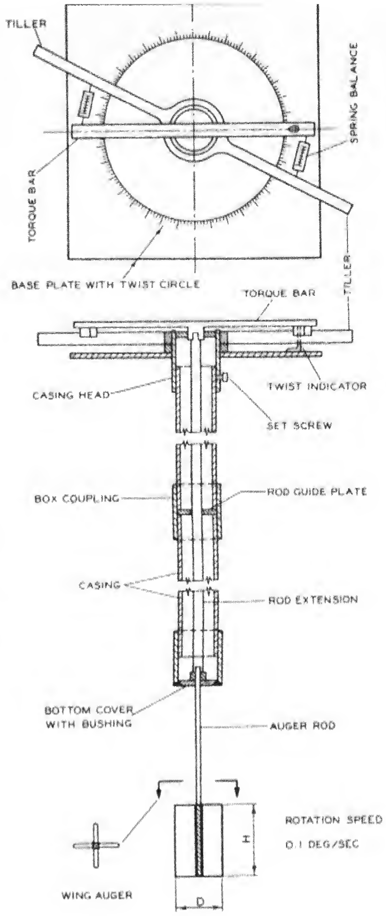
"INSITU" APPARATUS IN OPERATION

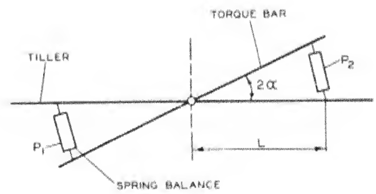


W. KJELLMAN – STATENS GEOTEKNISKA INSTITUT – STOCKHOLM, 1946

KJELLMAN "INSITU" APPARATUS

FIG. 17-A



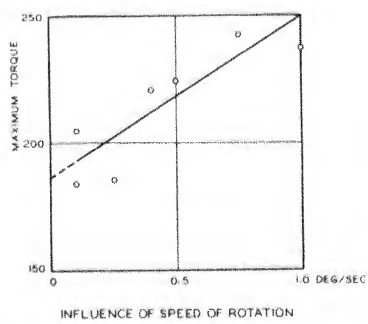


$$\text{TORQUE} \quad M = (P_1 + P_2) \cdot L \cdot \cos\alpha$$

$$M = \tau\left[\pi \cdot D \cdot H \cdot \frac{D}{2} + 2 \cdot \frac{\pi}{4} \cdot D^2 \cdot \frac{2}{3} \cdot \frac{D}{2}\right] = \tau \cdot \frac{\pi}{2} \cdot D^2 (H + \tfrac{1}{3} D)$$

$$\tau = \frac{M}{C}$$

τ = SHEARING STRESS C = AUGER CONSTANT



INFLUENCE OF SPEED OF ROTATION

LYMAN CARLSON: PROC. II CONF. SOIL MECHANICS, 1948, VOL. I, P. 265

CARLSON WING AUGER

FIG. 17-B

that the equipment is light, anchorages are not required, and a continuous resistance record is obtained. The withdrawal resistance may in some cases be influenced by a squeezing-in of the hole and friction between wire and soil.

Currently the Swedish Geotechnical Institute is conducting experiments with a wing type auger, shown in Fig. 17B and developed by **Lyman Carlson** (631). The casing with the auger abutting against the bottom cover plate is driven to the desired depth, the auger proper is then pushed down until it is beyond the zone of disturbance below the casing, the torque transmission and measuring equipment is attached to the rod, and the torque required to rotate the auger is determined and the corresponding shearing resistance computed. The method appears to give more reliable results than the wire and resistor method, it indicates a consistent increase in shearing strength with increasing depth in uniform soils, and good agreement between the computed, average shearing strength in actual slides and that obtained with the wing auger has been obtained in two cases so far investigated.

2.10 Borings -- General

In accordance with the method used in displacing or removing material in advancing a bore hole, the commonly used boring methods may be classified in the following six groups:

1. Displacement Boring
2. Wash Boring
3. Percussion Drilling
4. Rotary Drilling
5. Auger Boring
6. Continuous Sampling

The principal characteristics of these methods are summarized in Table 3 and will be discussed in greater detail in the following sections.

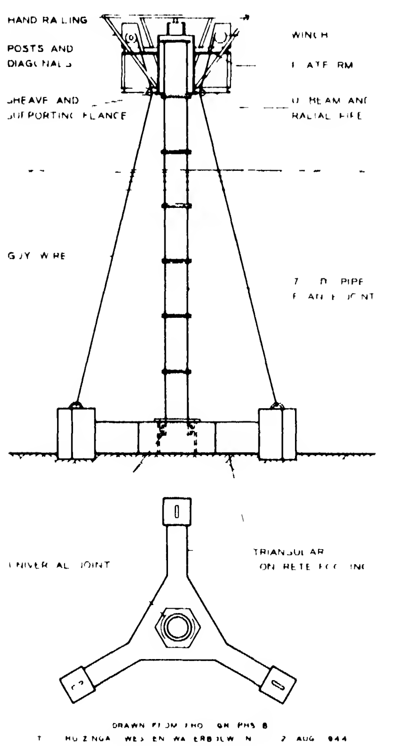
The efficiency of the various boring methods varies greatly with the character of the material to be penetrated and with the diameter and depth of the hole, several methods are often used in advancing a single bore hole. In selecting the boring method to be used, consideration should be given to (1) the material encountered and the relative efficiency of the various boring methods, (2) the facility and accuracy with which changes in the soil and ground-water conditions can be determined, and (3) possible disturbance of material later to be sampled.

The essential equipment for boring consists of (1) the actual drilling or sampling tools and clean-out equipment, (2) drill rods or cables connecting these tools to the operating equipment at the ground surface, (3) casing when required to stabilize the hole and a drop hammer for driving the casing, (4) motors and winches for lowering, operating, and withdrawing drilling tools, drill rods, and casing, (5) a tripod or mast of wood or pipe sections to permit handling of reasonably long sections of drill rods and casing, and (6) a pump when required for circulation of water or

drilling fluid to remove material from the bore hole.

The operating machinery and the pump may be used as independent units, but they are often assembled in a single drilling rig which may be mounted on skids or on a truck, on which a collapsible mast also may be erected. Truck-mounted drilling rigs are being used on an increasing scale because of their mobility and the reduction in time required for setting up and dismantling the equipment, but skid-mounted drilling rigs or independent units must be used in locations inaccessible by motor vehicles Drilling rigs are generally designed for one particular boring method and examples of such rigs will be given in the following sections, however, these rigs can, as a rule, also be used for other boring methods and for operation of samplers.

For exploration of water-covered areas the drilling equipment may be erected on a platform supported by piles, on a raft consisting of a platform supported by small boats, pontoons, or empty oil drums, or on a barge or drill boat The raft or barge is generally provided with a well in the center through which boring operations are performed Casing is used, at least through the open water. The raft or barge must be securely anchored and in such manner that it can rise or fall with changing water levels, the casing must also be shortened or extended in accordance with these levels These operations may be very time consuming in case of great tidal fluctuations of water levels, and drilling operations from a raft or barge may become impossible in case of swift currents and considerable wave action



DELFT ADJUSTABLE SOUNDING MAST

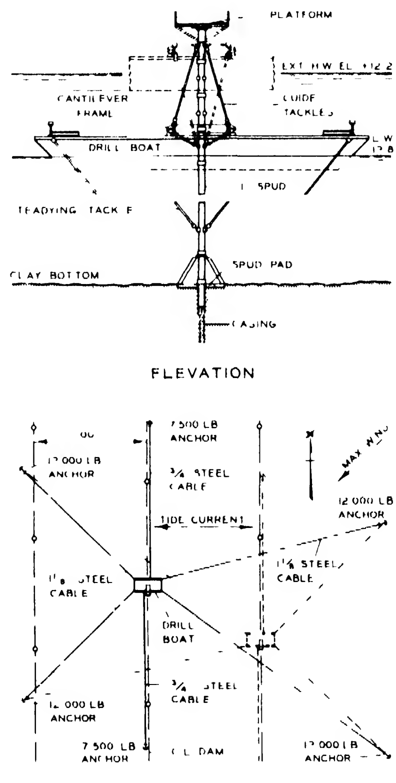
FIG 18

Under the above mentioned difficult conditions a boring tower or mast, supporting the operating platform, may be erected on pontoons which are ballasted and sunk to the bottom. The mast or tower must be sufficiently high to bring the platform above high-water level A slight slope or minor irregularities of the bottom may be compensated for by varying the amount of water in the individual pontoons or compartments and thereby the settlement of the pontoons in fairly soft deposits In case of a considerable slope of the bottom or firm deposits, it may not be possible to bring the mast or tower into vertical position by this method, and it will then be necessary to change the angle between the mast and the pontoons or between the mast and the platform in order to bring the latter into horizontal position.

An adjustable mast with platform for use in sounding operations on water-covered areas has been developed by engineers of the Soil Mechanics Laboratory in Delft -- **Huizinga (937)** -- and is shown in Fig. 18. The platform is supported by a heavy pipe which in turn is connected to a heavy triangular concrete

footing by means of a universal joint The pipe is brought into vertical position by means of three guy ropes and winches. The assembly is moved to a new location by placing a barge on each side and lifting the footing slightly off the bottom. The same principles can, of course, also be used for supporting a boring platform.

An arrangement used by the Corps of Engineers for exploration through deep water with a maximum tidal range of 28 ft, currents up to 8 knots an hour, and 6-ft high waves is described by Dow (318) and shown in Fig 19. The platform is carried by a 21-in heavy pipe, which in turn is supported by a circular plate or spud pad and by a short penetration into the bottom deposits A large boat is anchored alongside the pipe, and lateral forces on the pipe are taken up by guy ropes or tackles to hand-operated winches on the boat These winches are constantly manned so that the guy ropes will always be adjusted to varying water levels and currents.



PASSAMAQUODDY DRILL BOAT AND MAST

FIG 19

2.11 Stabilization of Bore Holes

Common to all boring methods is the problem of preventing caving of the sides and bottom of the hole and to avoid disturbance of the soil to be sampled

Uncased, dry bore holes are generally stable when they are shallow and above the ground-water table, but danger of caving increases rapidly with depth and the presence of free ground water In firm, cohesive soils the hole may nevertheless remain open for a limited length of time Bore holes without any provisions for stabilization and extending below ground-water level are often used in displacement boring and continuous sampling with piston samplers and slit samplers

Stabilization with water.- Bore holes are often filled with water to stabilize the hole and, when the water is circulated, to remove material ground up by the boring tools Water in the bore hole counteracts soil and pore-water pressures, but its ultimate effect depends on whether the soil is partially or fully saturated. In the partially saturated zone above ground-water level the soil derives a great part of its strength from capillary forces and the resultant apparent cohesion. Free water in the bore hole will eliminate this apparent cohesion and cause an increase in water content of the soil in the vicinity of the hole. The resultant loss in strength will generally be greater than the increase in strength caused by seepage pressure, and the ultimate result may be sloughing and collapse of the hole On the other hand,

the water will exert a stabilizing effect on the parts of the hole extending below ground-water level, it will temporarily increase the rate of swelling but decreases the ultimate amount of swelling of the soil in the vicinity of the hole, see also Section 4 2 Water alone cannot prevent caving of borings in soft or cohesionless soils nor a gradual squeezing-in of a bore hole in plastic soils Uncased bore holes filled with water are generally used in rock and often in stiff, cohesive soils

Stabilization with drilling fluid.- An uncased bore hole can often be stabilized by filling it with a properly proportioned drilling fluid or "mud", which when circulated also serves to remove ground-up material from the bottom of the hole A satisfactory drilling fluid can occasionally be obtained by mixing locally available fat clays with water, but it is usually advantageous and often necessary to add commercially prepared products such as Volclay or Aquagel When suitable native clays are not available, the drilling fluid is prepared with commercial products alone. These mud-forming products consist of highly colloidal, gel-forming, thixotropic clays -- primarily bentonite -- with various chemicals added to control dispersion, thixotropy, viscosity, and gel strength Special chemicals must be added to prevent flocculation when formations containing salt or anhydrite are encountered, or a drilling fluid consisting of a saturated solution of salt or sodium sulphate is used A drilling fluid prepared of water and Aquagel requires from 5 to 10 percent by weight of Aquagel, but this amount may be reduced to 1 to 5 percent when suitable native clays also are used Additional Aquagel should be mixed with the drilling fluid from time to time to replace losses of colloids by formation of the "mudcake" and by adherence of colloids to the cuttings which are removed from the bore hole

The stabilizing effect of the drilling fluid is caused in part by its higher specific gravity, in comparison with water alone, and in part by the formation of a relatively impervious lining or "mudcake" on the side walls of the bore hole This lining prevents sloughing of cohesionless soils and decreases the rate of swelling of cohesive soils The drilling fluid also facilitates removal of cuttings from the hole on account of its greater specific gravity and viscosity The required velocities and volume of circulation are smaller than for water alone, and the danger of uncontrolled erosion at the bottom of the hole is thereby decreased. Furthermore, the drilling fluid is thixotropic, that is, it stiffens and forms a gel when agitation is stopped, and it can be liquified again by resuming the agitation. It is thereby better able than water to keep the cuttings in suspension during the time required for withdrawal and re-insertion of boring and sampling tools. It also reduces abrasion and retards corrosion of these tools

Weighting materials, consisting of ground barite, hematite, galena, or other heavy minerals, are added to the drilling fluid to increase its specific gravity and prevent caving of the hole in troublesome soils or when the fluid must carry very coarse-grained materials in suspension These weighting materials are available in specially prepared form and sold under various trade names, such as Baroid and Colox The unit weight can in this manner be increased up to 150 lb per cu ft, but this is rarely required in the relatively shallow borings for civil engineering purposes.

Drilling fluid may be lost when cavities or highly permeable strata, such as clean gravel, are encountered, especially when there is also a strong ground-water flow. This loss can often be stopped and circulation regained by adding cement, straw, cotton seed hulls, or special, commercially prepared fibrous materials to the fluid. These materials will be deposited in and seal off the pervious strata

Counteracting the above mentioned advantages of drilling fluid and in comparison with clear water are the following disadvantages: (1) it makes identification of the cuttings and thereby of the soil at the bottom of the hole more difficult and uncertain; (2) it hinders observation of ground-water levels and pressures and field determinations of the permeability of the soil, and (3) it requires greater fluid passages in pumps, drill rods, and core barrels Drilling fluid is primarily used with rotary drilling and core boring methods

Stabilization with casing.- Casing or the lining of the bore hole with steel pipe provides the safest, though relatively expensive, method of stabilizing the bore hole Many types of standard and special pipe are used as casing and are described in detail in Chapter 8 Standard or Extra Strong Black Pipe is generally preferred for exploratory borings in soil since it is readily available

Some typical joint details are shown in Fig 20. Recessed outside couplings, A and B, provide the strongest joint and are commonly used in soils The open joint, A, is used under normal conditions, but the butt joint, B, is often preferred when the casing is to be driven through hard ground and ahead of the boring Repeated use will damage the threads of open joints and cause beading and upsetting of butt joints After a certain depth of bore hole is reached or when difficult ground conditions or obstructions are encountered, it is often impossible to advance the original string of casing any further A smaller casing is then inserted through the one in place, and the diameter of the extension of the bore hole must be decreased accordingly Flush or practically flush jointed casing, C, is often used in order to minimize the required decrease in diameter Flush jointed casing has a smaller resistance to driving and withdrawal than casing with outside coupling The joint detail shown in Fig 20D is often used in cohesionless soils when the casing is to be advanced by rotation, jacking, and jetting instead of by blows of a drop hammer

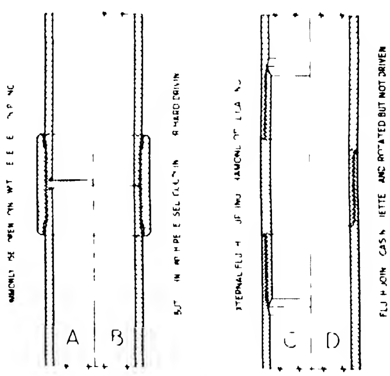


FIG 20 CASING COUPLINGS

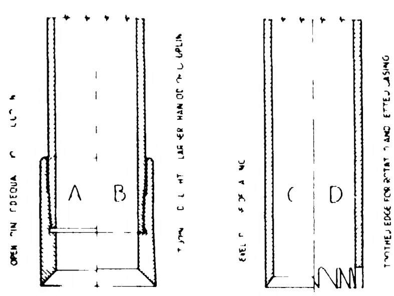


FIG 21- CASING SHOES

The lower end of the casing is generally protected by a casing shoe of hardened steel, Fig 21A and B, and with an inside bevel so that displaced material will be forced into the pipe.

Removal of this material instead of pushing it aside decreases friction between the casing and the surrounding soil. In case of flush jointed casing, the shoe may simply consist of a short section of pipe. It is often bevelled or, when the casing is advanced by combined rotation and jacking, provided with rough cut teeth, Fig. 21C and D.

Except when undisturbed samples are to be obtained of soils which are sensitive to vibration, the casing is generally driven by repeated blows of a drop hammer, Fig 22. The hammer is guided by a pipe or rod, and the blows are transmitted to the casing through a drive head The upper end of the guide tube in Fig. 22A has a heavy coupling or jar collar, so that withdrawal of the casing can be facilitated by upward blows of the hammer When used with wash boring, the drive head often has a side outlet for the wash water, and the hammer may be slotted so that it can be used without withdrawing the drill rod, Fig 22B These features facilitate concurrent advance of casing and bore hole Heavy casing is lifted into driving position by means of a casing elevator, Fig 23, but a hoisting plug, similar to that shown in Fig 26, is generally used for light casing The casing clamp, Fig 24, serves to

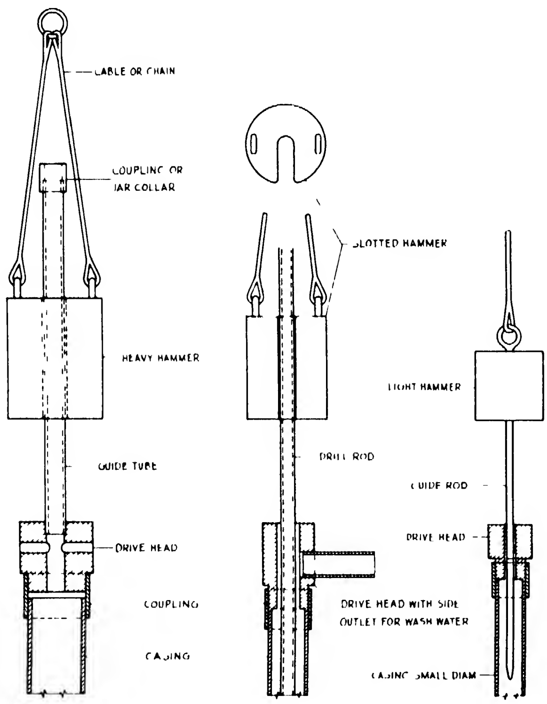


FIG 22 - DROP HAMMERS AND DRIVE HEADS

FIG 23 CASING ELEVATOR

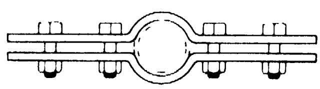


FIG 24 - CASING CLAMP

prevent uncontrolled downward movement of casing inserted in an oversize bore hole or when there is danger of undercutting. It also facilitates the use of jacks in pulling the casing

Casing will prevent caving of the sides but not always of the bottom of a bore hole. The stability of the bottom can be increased by keeping the casing filled with water or drilling fluid. However, the casing should not be filled with water when

the bottom of the bore hole is above the ground-water level and undisturbed samples are to be obtained. Casing is used extensively with wash borings, percussion drilling, and deep auger borings. It is generally required for all borings in very soft soils, when large open drive samplers are used, and when accurate observations of the ground-water levels or incidental field permeability tests are to be made

Stabilization by freezing.- A bore hole may be stabilized by freezing the soil around it as the boring progresses This may be accomplished by replacing wash water with kerosene or brine, cooled by means of "dry ice". The method cannot be used when the ground is dry or nearly so and when there is a strong ground-water flow So far, it has only been used in a few cases and primarily for experimental purposes

Another freezing method consists in circulating the cooling liquid through a series of pipes, driven or bored into the ground in a circle around the main bore hole, which subsequently is advanced by core boring This method is expensive, but it has been used successfully when large undisturbed samples of gravelly soil or weak and fissured rock could not be obtained by other and cheaper means

Stabilization by grouting.- A bore hole passing through a troublesome zone in rock -- cavities, faults, fissured and broken rock, etc -- may be stabilized by filling the lower part of the hole with cement grout and thereafter re-drilling the hole through the concrete plug The method can be used only when the hole remains open until the grouting is completed and the setting started Grouting is often preferred to the use of casing, since the diameter of the hole then can be maintained, whereas it must be reduced for any extension of the hole below the casing

2.12 Displacement Boring

The simplest of all boring and sampling methods consists in forcing a closed sampler -- slit, cup, or piston sampler -- into the soil until the desired depth is reached, whereupon the sampler is rotated or the piston released or withdrawn and a sample taken After withdrawal of the sampler and removal of the sample, the sampler is again inserted into the hole and forced down to the depth where a new sample is to be taken The bore hole is uncased and no attempt is made to stabilize it The sampler acts as a close-fitting piston, and its withdrawal creates a temporary, partial vacuum which often causes failure of bore holes in soft or cohesionless soils The closed sampler can generally be forced through the caved part of borings in soft soils without much difficulty, but caving in cohesionless soils often makes it necessary to use casing and advance the bore hole by other means until the troublesome zone is passed. In stiff or dense soils it is necessary to use fairly continuous sampling, otherwise the sampler may be damaged, or it requires objectionably heavy construction

Major changes in the character of the soil can be detected by means of the penetration resistance of the sampler, but the determination of such changes and

thereby the depths at which samples should be taken is not always as accurate and reliable as when other boring methods are used. The forcing of a closed piston sampler into the soil will cause disturbance of the soil below the sampler but, in contrast to the disturbance caused by other boring methods, there is no mixing of the soil layers or segregation of the soil constituents, and the disturbance seldom extends to a depth below the sampler greater than three times the outside diameter of the sampler.

Displacement borings are generally from 1 to 3 in in diameter Larger diameters are impractical since they require samplers of too heavy construction The method should not be confused with the use of piston samplers in cased bore holes or in uncased holes, which have been advanced by other means and reamed out so that clearance between the sampler and the walls of the hole is provided, and so that the hole can be stabilized with water or drilling fluid Displacement boring is simple and economical when excessive caving of the hole does not occur. It is being used extensively in the Scandinavian countries, California, Louisiana, and other regions It is well suited for reconnaissance explorations and, when soil conditions are favorable, for detailed explorations

2.13 Wash Boring

A wash boring is advanced partly by a chopping and twisting action of a light bit and partly by jetting with water which is pumped through the hollow drill rod and bit, Fig 25 Cuttings are removed from the hole by the circulating water The drill rod and bit are moved up and down by pulling and slackening the rope and are at the same time rotated back and forth by means of the tiller These operations, as well as the pumping, may be performed entirely by hand, but a small motor-driven winch and pump are generally used The water may be pumped from a river or pond or taken directly from local water supply lines, when such sources are near the bore hole, but a closed circulating system is generally preferable In the latter case water is pumped from a small sump or a tub, and the soil-laden water from the bore hole is discharged into the same reservoir, where the coarse material settles out and from which the so-called "wet samples" can be secured

The drill rod is generally 1-, 1-1/2-, or 2-in Standard Black Pipe with recessed couplings, Fig 27, but Standard Diamond Core Drill Rods, see Section 8.4, are occasionally used During coupling and uncoupling the drill rod is supported by a fork, Fig. 28, resting on the casing. The straight bit, Fig 29, is commonly used, but the other bits shown in the same figure are useful when obstructions or special soil conditions are encountered and for increasing the diameter of the hole below the casing and thereby facilitating its advance Casing is required in soft or cohesionless soils, but is often omitted in stiff, cohesive soils when only small representative samples are desired

Changes in the character of the soil are determined partly by the feel of the

tiller or the resistance to penetration and rotation of the bit and partly by examination of the cuttings in the wash water as it emerges from the casing, but definite identification of the soil can only be made when representative samples are taken from the bottom of the bore hole. When such samples are taken, the method is often called "dry sample boring" to distinguish it from "wet sample boring" or more appropriately "wash sample boring", during which only samples from the washed and segregated material in the tub are taken These samples are worthless and non-representative unless special arrangements are made to preserve all the material from a particular stratum and to exclude material from other strata

The soil below the bottom of the bore hole may be disturbed by careless handling of the bit and by excess erosion when the flow of the wash water is not properly controlled Coarse, segregated material tends to collect at the bottom of the hole, and sticky soils may adhere to the casing instead of being removed by the wash water Careful cleaning of the hole is therefore required before samples are taken

The principal advantages of the wash boring method are that it can be used in borings of both small and large diameter, that the equipment is inexpensive and light, and that the method does not cause sealing of the bottom of the hole and therefore does not obstruct ground-water observations The rate of progress is relatively slow except in very soft soils and fine- to medium-grained cohesionless soils. It can be

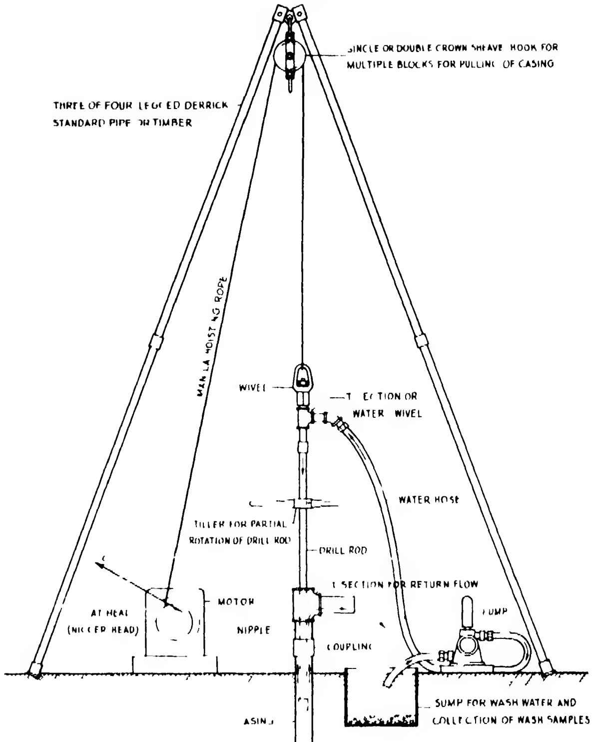
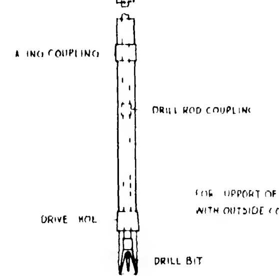



FIG 25 WASH BORING

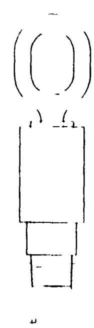


FIG 26 HOISTING PLUG

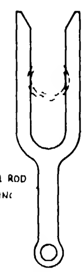


FIG 28 FORK

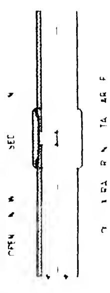


FIG 27 DRILL ROD

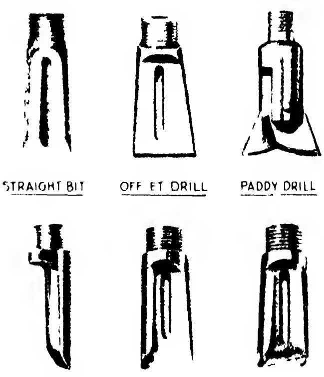


FIG 29 WASH BORING BITS

used in all common soils which do not contain numerous stones or boulders, but it is not suitable for boring in hard and cemented soils or rock.

Drillers with adequate experience in wash boring can determine changes in and estimate the general character of the soil with satisfactory accuracy, especially when both the drill rod and the pump are operated entirely by hand On the other hand, very serious mistakes may be made by inexperienced or careless drillers, who often fail to recognize changes in the character of the soil, do not clean the bore hole properly, and take samples of the coarse and segregated material settled at the bottom, instead of the undisturbed material below the bottom The results of such errors are very misleading soil profiles which often indicate strata of coarse materials at depths where soft soils of low bearing capacity actually exist

Wash boring is used extensively for reconnaissance explorations and, in some regions, also for advancing and cleaning the bore hole between samples taken in detailed and special explorations. However, the method should not be used above ground-water level when undisturbed samples are desired of the soil above this level, since the water will enter the soil below the bottom of the hole and change its water content

2.14 Percussion Drilling

Advance of a bore hole by percussion drilling is accomplished by alternately raising and dropping a heavy drilling bit -- also called a churn bit, Fig 34 -- which is attached to a drill stem, Fig 32 In caving soil or broken rock, where there is danger of the bit becoming stuck, a jar and sinker bar are connected to the top of the drill stem, Fig 30 Such a "string of tools" for a 6-in hole may weigh from 1000 to 2000 lb and is attached to and operated by a "soft laid" cable or wire rope The method is therefore often called "cable tool drilling" Other names for the method are "churn drilling" on account of the churning action of the drilling bit, or "well drilling" because it was one of the principal methods used in sinking water and oil wells, but it has been replaced by other methods to a large extent

The chopping action of the drilling bit may be obtained by taking a few turns with the main cable around the cathead of a winch and varying the pull on the free end of the cable, as in operating a wash boring bit However, the up and down motion of the cable is generally imparted by means of a "jerkline" or by attaching it to a crank, a spudding arm, or a walking beam Compact, motorized, and truck- or skid-mounted drilling rigs are now used extensively The spudding arrangement of one such unit is shown diagrammatically in Fig 30 and a photograph of another and slightly different unit in Fig 31 The spudding arm is provided with a heavy coil spring or dash pot, which lessens the shock transmitted to the cable and operating machinery and starts the lifting of the bit immediately after the blow has been delivered. Strokes vary from 18 to 40 in. in length and from 35 to 65 per minute according to the soil or rock conditions.

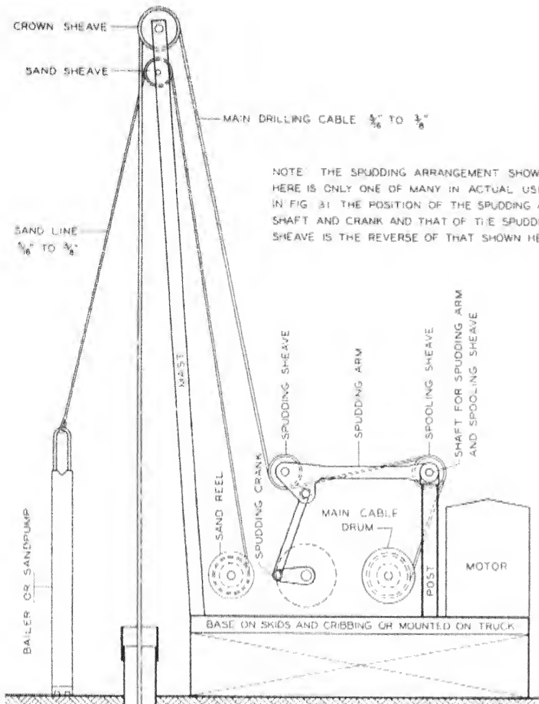
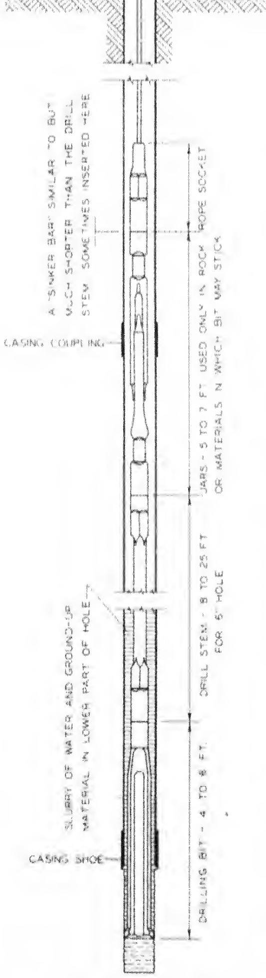



FIG. 30 - PERCUSSION DRILLING

FIG. 32 - DRILL JARS AND STEM

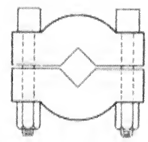


FIG. 33 - CASING DRIVE CLAMP

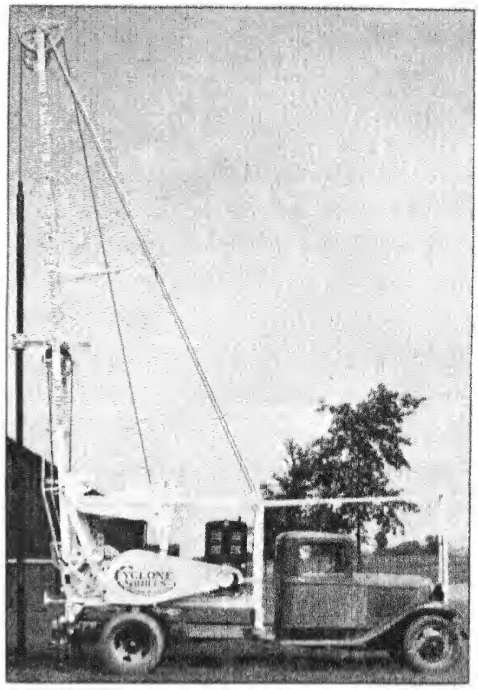
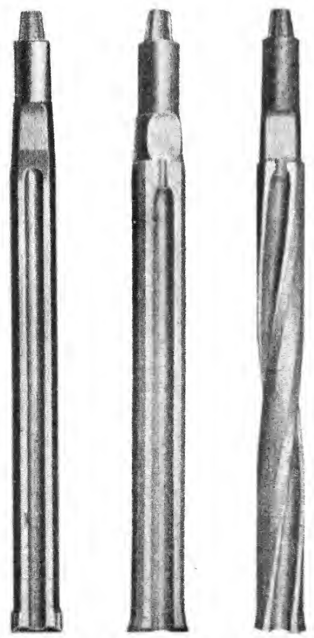
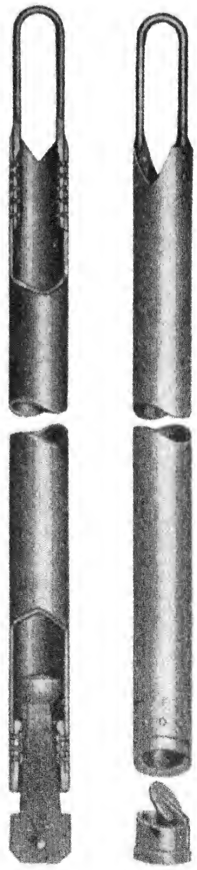


FIG. 31 - KEYSTONE PERCUSSION DRILLING RIG



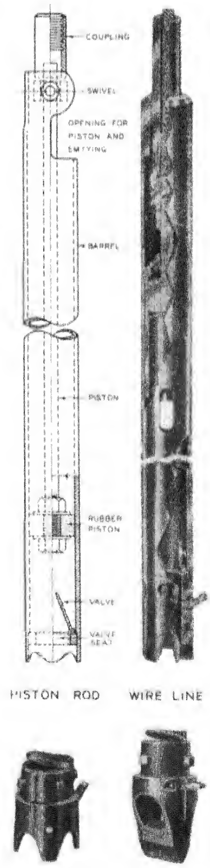
REGULAR MOTHER HUBBARD TWISTED

FIG. 34 - PERCUSSION DRILLING BITS



DART VALVE DISK VALVE

FIG. 35 - BAILERS



PISTON ROD WIRE LINE

REGULAR BIT BOTTOM

FIG. 36 - SANDPUMPS

The bore hole is generally kept dry except for a small amount of water which forms a slurry with the material ground up by the bit When the carrying capacity of the slurry is reached, the bit is withdrawn and the slurry removed by means of a bailer or sandpump, Fig 35 and 36, which are operated by a separate winch and light cable, also called a "sandline". In soft soils and cohesionless soils it is often possible to advance the hole by means of the bailer or sandpump alone, especially when they are provided with a dart valve or bit bottom A small amount of sand is sometimes added to increase the cutting action of the bit in fat clays, whereas clay may be added to increase the carrying capacity of the slurry when drilling in coarse, cohesionless soils. Specially prepared drilling fluid is also used for the latter purpose, particularly when there is danger of excessive loss of water in pervious formations.

Casing is generally required, except in stable rock, and is driven by attaching a drive clamp, Fig. 33, to the main drill stem Whenever possible, the bore hole is advanced ahead of the casing for a depth somewhat less than the length of a string of tools, but it is difficult and often impossible to advance the hole ahead of the casing in soft soils or cohesionless soils. Caving in such soils may occur even when the casing is advanced ahead of the hole Stabilization may then be obtained by filling the boring with water or drilling fluid, but the efficiency of the method is thereby decreased, and other boring methods and especially rotary drilling are generally preferred where such troublesome formations are prevalent

Changes in the character of subsurface materials are determined by the rate of progress, action of the drilling tools, and composition of the slurry However, the character of the material cannot be determined as accurately as with wash boring and especially not when foreign materials have been added to the slurry. Furthermore, the cuttings are removed only intermittently and therefore represent the average material over a considerable depth The slurry may enter the soil below the bottom of the hole thus hindering ground-water observations. The main drilling bit and bailers or sandpumps with dart valves or bit bottom may disturb the soil to a considerable depth below the bottom of the hole, and the suction caused by operation of a sandpump may cause caving or mixing of strata of soft or cohesionless soils

Percussion drilling is the oldest of all methods for drilling deep bore holes Its principal advantages are simplicity of equipment and operation, use of a cable instead of drill rods, and that only a small amount of water is required. The method can be used in most soils and rock, and it is superior to other methods in penetrating coarse gravel deposits, in formations containing numerous boulders and chert nodules, and in cavernous rock The method is relatively slow in clay and sticky shale and is often impossible to use in fine, loose sand or quicksand The pure cable tool method is not economical for borings less than 4 in. in diameter, and it is not well suited as a general method for exploratory boring on account of difficulties in detecting thin strata and small changes in the character of the soil, and because drilling tools may disturb the soil to be sampled. In combination with auger or wash

borings, the method may be used to advantage for penetrating occasional hard layers, coarse gravel, boulders, and other obstructions It may also be used for extending such borings into rock when undisturbed samples or cores of the rock are not required. A combination of auger boring and percussion drilling is often used for foundation explorations in Europe

2.15 Rotary Drilling

In rotary drilling the bore hole is advanced by rapid rotation of the drilling bit, which cuts, chips, and grinds the material at the bottom of the hole into small particles The cuttings are removed by pumping water or drilling fluid from a sump down through the drill rods and bit and up through the hole, from which it flows first into a settling pit and ultimately back to the main pit Water alone may be used when the depth is small and the soil is stable, but drilling fluid is generally preferred since the required flow is smaller and it serves to stabilize the hole. A section of casing is used to start the hole, but the remaining part of exploratory bore holes advanced by rotary drilling is usually uncased except in soft soils.

When rotary drilling is used for exploratory boring, the motors, rotary driving mechanism, winches, pump, etc , are generally assembled as a unit and with a folding mast mounted on a truck or tractor, or the unit may be mounted on intermediate skids so that it can be placed on a raft or moved into places inaccessible by motor vehicles A diagrammatic sketch of such a drilling rig is shown in Fig. 37 and a photograph of a similar unit -- manufactured by the George E Failing Supply Co., Enid, Oklahoma -- in Fig 38 The skid-mounted drilling machines shown in Fig. 127 and 129 can also be used for rotary drilling In large stationary drilling rigs, as used in production drilling for oil, the drill rod is rotated by means of a rotary table, and this method is occasionally used in portable drilling rigs, Fig. 56 and 57

The rotary drive of the commonly used, portable, rotary drilling rigs, Fig. 37, consists of a "drive quill" with a hexagonal bore and connected to the drive shaft from the motor by spiral bevel gears A hollow, hexagonal drive rod can slide through and is rotated by the drive quill. A swivel joint connects the upper end of the drive rod to a yoke which can be moved in a vertical direction by two hydraulic cylinders. The drill rod slides through the hollow drive rod and is gripped by a chuck at the lower end of this rod The bit pressure and the rate of feed can then be controlled by means of the hydraulic cylinders

The upper section of the drill rod is often replaced with a "kelly" or "grief stem" which is a thick-walled pipe with external, longitudinal grooves. Keys or drive pins in a kelly drive bushing on top of the drive rod fit into these grooves and rotate the kelly, even when the latter is not clamped to the drive rod. The assembly can then be operated by gravity and the rate of feed controlled by a wire line to the hoist. Clamping of the drill rod and re-setting of the hydraulic cylinders after

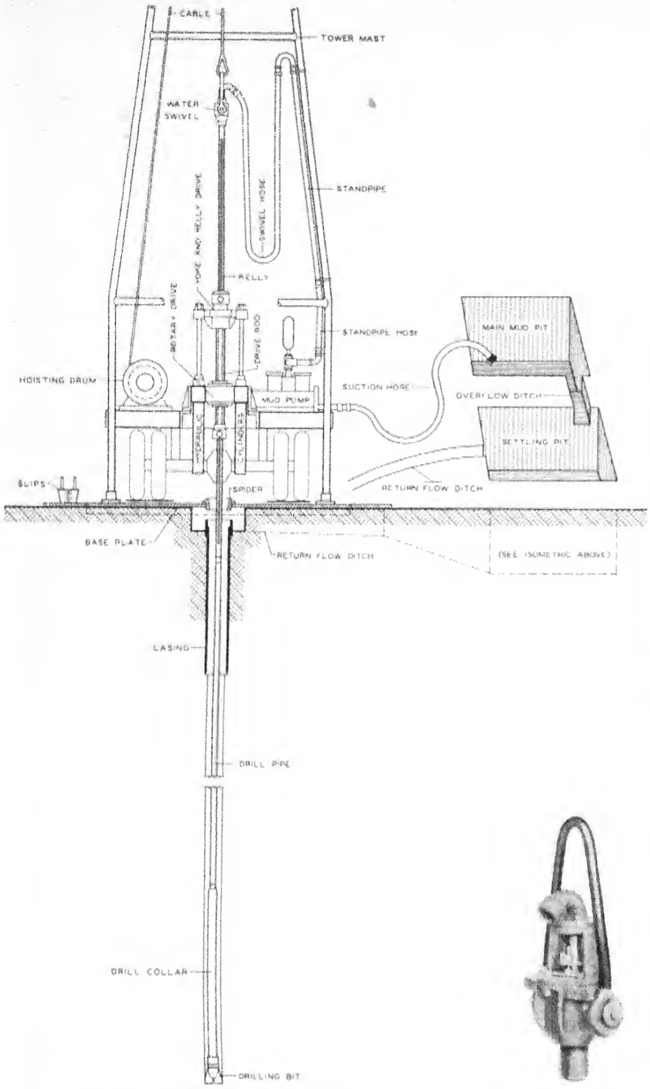


FIG 37 - ROTARY DRILLING

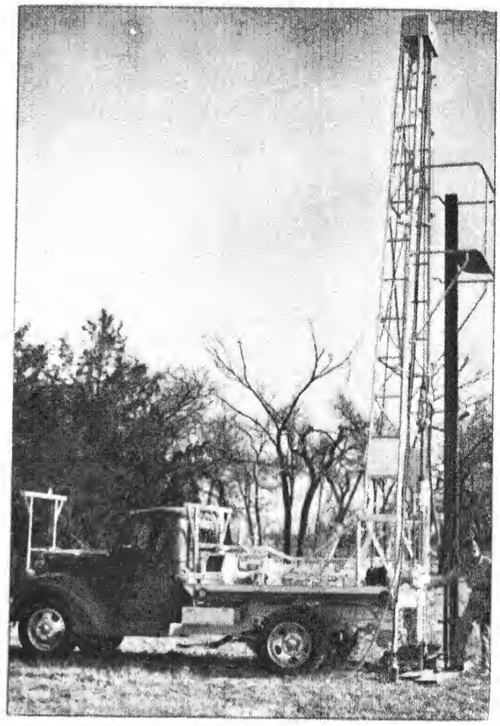


FIG 38 - TRUCK MOUNTED ROTARY DRILLING RIG

WATER SWIVEL
FIG 40

HOISTING PLUG
FIG 41

FISHTAIL BIT
FIG. - 42

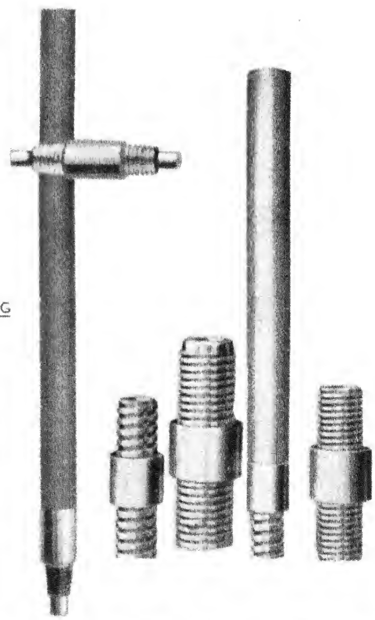
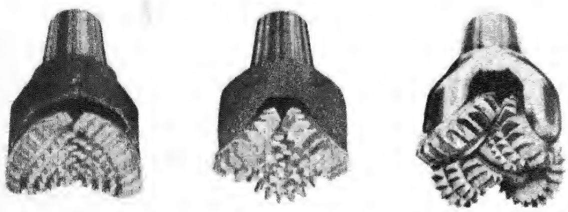


FIG. 39 - DRILL RODS AND COUPLINGS

TWO - BLADE BIT THREE - BLADE BIT FOUR BLADE BIT

FIG. 43 - BLADED BITS



TWO - CONE BIT TRI - CONE BIT ROLLER BIT

FIG. 44 - ROCK BITS

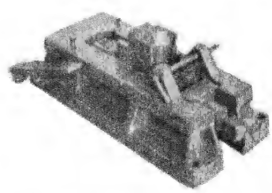


FIG. 45 - SAFETY CLAMP

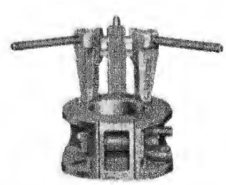


FIG. 46 - SPIDER AND SLIPS

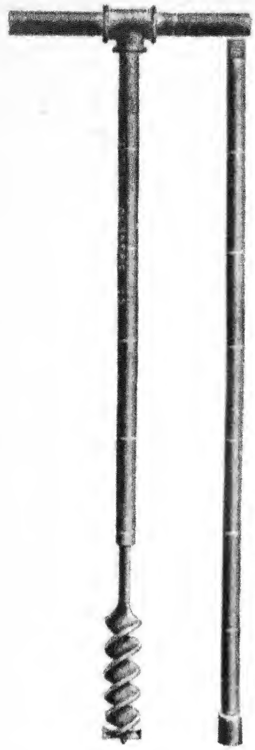
completion of each stroke is thereby avoided and a greater rate of progress obtained in soft materials When firm materials are encountered, the kelly is clamped to the drive rod by means of the chuck and additional feed pressure is exerted through the hydraulic cylinders

The upper end of the drill rod or kelly is connected to a water swivel, Fig 40, and through the hose and standpipe to the mud pump The drill head, comprising the rotary drive and the hydraulic feed mechanism, can be moved back, or in other drill rigs swung aside, to permit addition or removal of drill rod sections The mast is hinged and can be folded down over the truck when the rig is to be moved to a new location The movement of a sliding drill head and the raising and lowering of the mast are performed by means of separate hydraulic cylinders

Standard diamond core drill rods, Fig 39, are generally used in relatively shallow borings for civil engineering purposes, but heavier drill rods are required for deep borings of large diameter, see Sections 8 4 and 8 5 During the removal and addition of new sections, drill rods in the hole may be supported by a fork, Fig 28, if they have outside couplings, and external flush drill rods may be gripped by a wrench or chain tong if they are light and the boring is shallow, but a long string of heavy, external flush rods is supported by either a safety clamp, Fig 45, or by a spider and slips, Fig 46 The latter are also used when inserting a string of casing in an oversize bore hole The section of drill rod immediately above the bit often consists of pipe with a greater outside diameter and wall thickness than other sections and is called the drill collar The increase in stiffness and weight, thereby acquired, lends stability to the bit, decreases whip and vibration, and helps to keep the bore hole straight and uniform

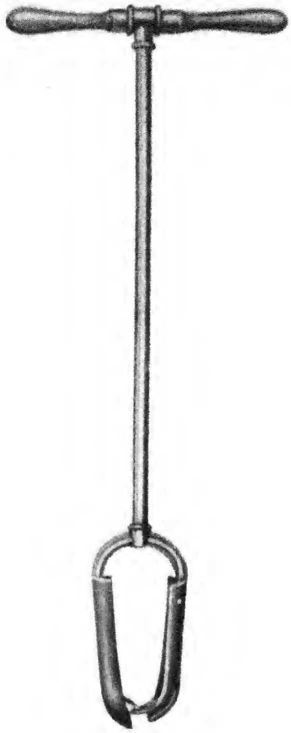
Many types of rotary drilling bits are used in accordance with the character of the material to be penetrated Fishtail bits, Fig 42, and two-bladed bits, Fig 43, are used in relatively soft soils and three- or four-bladed bits in firmer soils and soft rock The cutting edges are surfaced with tungsten carbide alloys or formed by special hard-metal inserts The bits used in rock all have several rollers with hard-surfaced teeth, Fig 44 The two-cone bits are used in soft or broken formations, but the tri-cone and roller bits provide smoother operation and are more efficient in harder rocks The number of rollers and also the number and shape of the teeth are varied in accordance with the character of the rock. Relatively few and large teeth are used in soft rock, and the teeth are interfitting so that the bit will be self-cleaning The teeth in all bits are flushed by drilling fluid flowing out of vents in the base of the bit

Rotary drilling is best suited for borings with a diameter of not less than 4 in., and a diameter of 6 to 8 in is generally preferred when the method is used for exploratory boring In most soils and rocks the rate of progress is greater than can be obtained by other methods However, rotary drilling is not well suited for use in deposits containing very coarse gravel, numerous stones and boulders or chert nodules, or in badly fissured or cavernous rock or very porous deposits with a strong



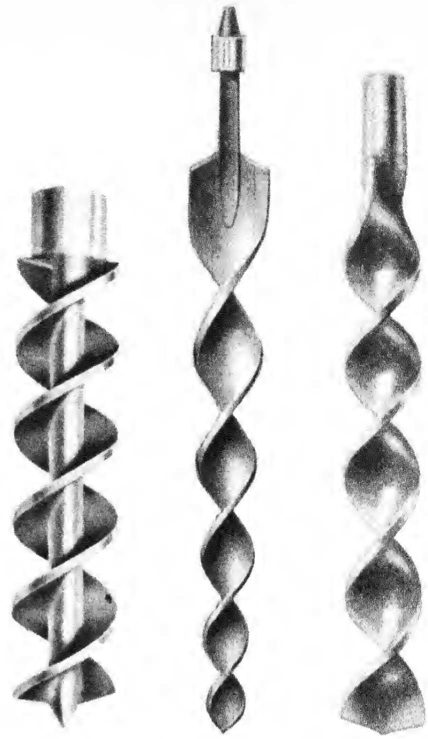
SMALL HELICAL AUGER

FIG. 47



POSTHOLE OR IWAN AUGER

FIG. 48

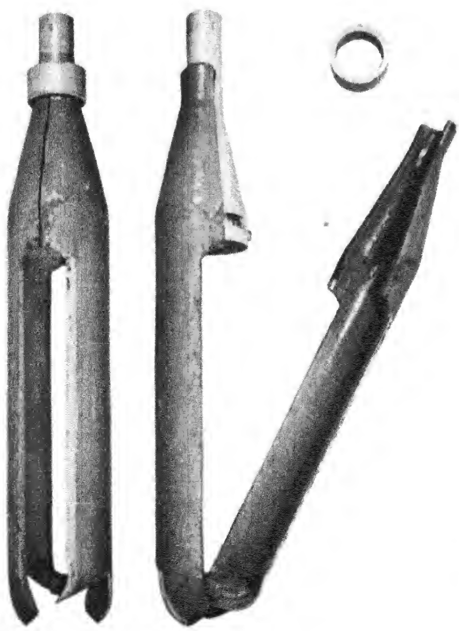


LARGE HELICAL OR WORM TYPE AUGERS

FIG. 49

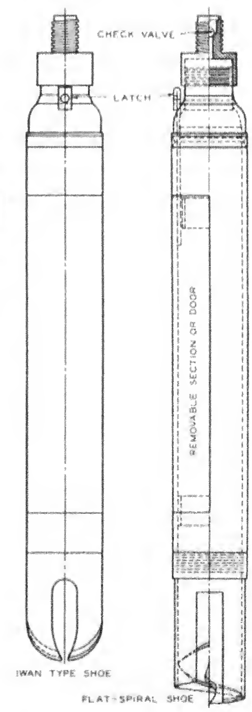
SPOON AUGER

FIG. 50



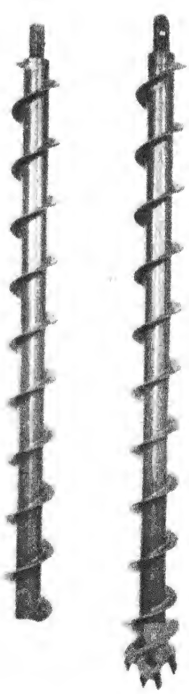
VICKSBURG HINGED AUGER

FIG. 51



SPRAGUE & HENWOOD BARREL AUGERS

FIG. 52



BUDA CONTINUOUS HELICAL AUGERS

FIG. 53

ground-water flow since an excessive amount of drilling fluid may be lost by seepage in such formations

A uniform, clean hole with relatively little disturbance of the soil below the bottom of the hole is generally produced An experienced driller can detect changes in the character of the soil or rock by the rate of progress and the action of drilling tools and by cuttings in the drilling fluid However, such changes cannot be determined as accurately as with wash borings, since power operation is required, and since drilling fluid, when used, makes identification of the cuttings more difficult The fluid also hinders ground-water observations and the performance of incidental permeability tests

Rotary drilling was originally developed for production drilling of deep oil wells and is generally associated with this use However, with the development of light and compact drilling rigs, the method is now also used extensively in explorations for oil and minerals and for drilling water wells In recent years rotary drilling has been used to a considerable extent in subsurface explorations for civil engineering purposes, but primarily as a method of advancing and cleaning the bore hole between samples of large diameter and less as a method for determination of the rough soil profile However, light rotary drilling rigs are employed on a much larger scale than rotary drilling proper, since these rigs also can be used for wash boring, occasional percussion drilling, operation of large augers, drive samplers, and core barrels, in drilling of shot holes for seismic methods of exploration, and for dewatering bore holes and field permeability tests In general, these drilling rigs constitute very flexible and useful units for subsurface exploration

2.16 Auger Borings

In auger boring the hole is advanced by rotating a soil auger while pressing it into the soil and later withdrawing and emptying the soil-laden auger Soil augers are used in subsurface exploration for three purposes (1) general exploration and obtaining of representative samples in reconnaissance surveys, (2) advancing and cleaning bore holes between depths at which undisturbed samples are to be taken by drive sampling methods, and (3) drilling large accessible bore holes which permit direct inspection of the soil in situ Augers are also used for various construction purposes, such as drilling drainage wells, pre-excavation for piles, and excavation for piers and caissons of relatively small diameter.

Augers used for the first purpose are generally small helical augers, Fig 47, and post hole or Iwan type augers, Fig 48 They are used primarily in soils in which the bore hole can be kept dry and uncased, and are hand-operated in shallow explorations The rate of progress is slow, but the method is employed extensively in subsurface exploration for highways, railroads, and airfields on account of its simplicity and the light and inexpensive equipment The augers are occasionally used at depths up to 100 ft and are then often power operated so that a much greater

rate of progress is obtained

Large helical or worm type augers, Fig 49, and spoon augers, Fig 50, in many different forms are used for the second purpose A recent addition to this group is a hinged auger, Fig 51, developed by the Waterways Experiment Station in Vicksburg It has a bit similar to that of the Iwan auger and is split in two halves, which are held together by a hinge in the bit and a ring at top This auger is very sturdy and seems to retain the soil better than other augers, and it is easily emptied of soil after opening the auger Auger borings are kept dry, as far as possible, since water in the hole increases the danger of losing the soil in the auger, and since the soil-laden auger acts as a piston and tends to force water above it out of the hole Casing is required for auger borings in unstable soil and especially when the boring is extended below the ground-water surface

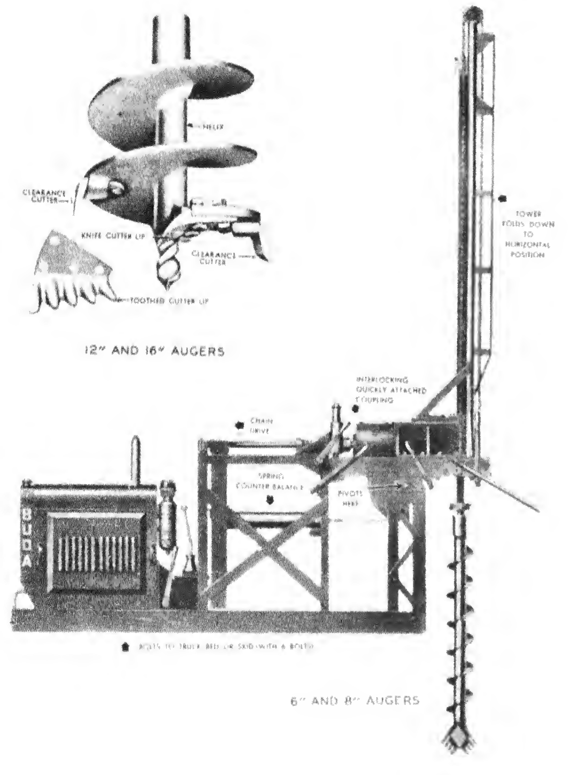
Boring with large, hand-operated augers is slow and cumbersome and seldom used in this country but to some extent in Europe However, the augers can be operated by portable rotary drilling rigs, described in the foregoing section, or by the drilling machines used for core boring, and they are then very efficient for boring in medium soft to stiff cohesive soils and in moist cohesionless soils with some apparent cohesion On the other hand, these augers are not well suited for use in very hard or cemented soils, and they often fail to retain very soft soils and fully saturated cohesionless soils When the last mentioned soil types are encountered, the casing is generally driven ahead of the hole and then cleaned out by means of barrel augers or, if there is water in the hole, with bailers or sandpumps

Barrel augers, Fig 52, consist of a short auger of the flat spiral or Iwan type surmounted by a barrel which serves as a reservoir for the soil The auger bits or shoes are interchangeable, the flat spiral is used in fine to coarse sand and the Iwan type in coarse sand, gravel, and stony soil The barrel can be emptied of soil either by unscrewing the shoe, for small augers, or through a removable or hinged section of the barrel In the latter case the auger is also called a "door" or "window" sampler -- **Sprague and Henwood (174, 175).** Barrel augers are seldom used as a primary means of advancing the bore hole but mainly for penetrating relatively thin strata of troublesome soils, for cleaning the bore hole of coarse sand, gravel, and stones, and for obtaining fairly representative samples of these materials

A series of augers and special drilling machines for their operation has been developed by the Buda Company, Harvey, Illinois These augers are primarily intended for construction purposes, but they are also used for foundation exploration The continuous flight, helical augers, Fig 53, are used for drilling holes with a diameter of 6 to 8 in and a depth up to 100 ft As depth increases, new auger sections are added instead of drill rods. The material is thereby automatically transported to the ground surface, repeated withdrawals of the auger are eliminated, and the rate of progress increased However, it is more difficult to determine definitely the depth from which the soil, discharged by the auger, was excavated. The auger has interchangeable heads or bits for use in various types of material It is operated by the

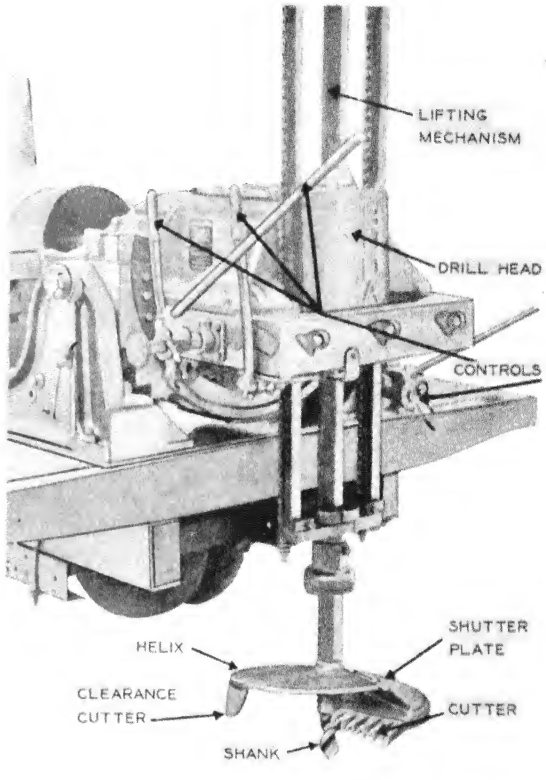
drilling machine shown in Fig 54, which has a folding mast with chain-operated feed and lift Relatively short helical augers with interchangeable cutters, upper left-hand corner in Fig 54, are used for medium-sized holes, 12 to 16 in in diameter, whereas holes up to 42 in in diameter are excavated by means of a disc auger, Fig 55

Large-diameter, accessible bore holes may be excavated by the above mentioned disc augers, but bucket augers are generally used when these holes are deep The bucket auger consists of a relatively short barrel, which is open at the top The bottom is split and bent to form a flat spiral and provided with a hinge and



BUDA EARTH DRILL WITH CONTINUOUS HELICAL AUGERS

FIG 54

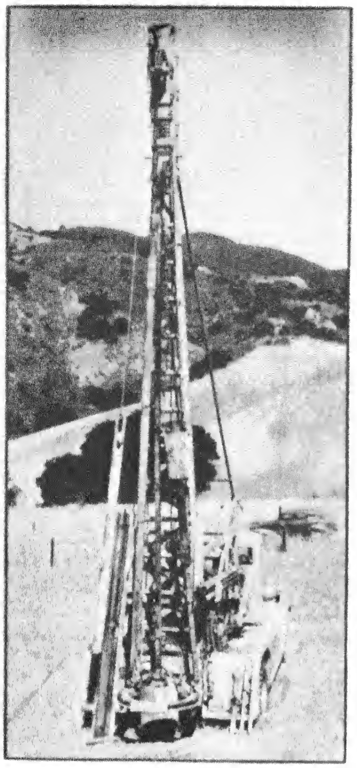


BUDA EARTH DRILL WITH DISK AUGER

FIG 55

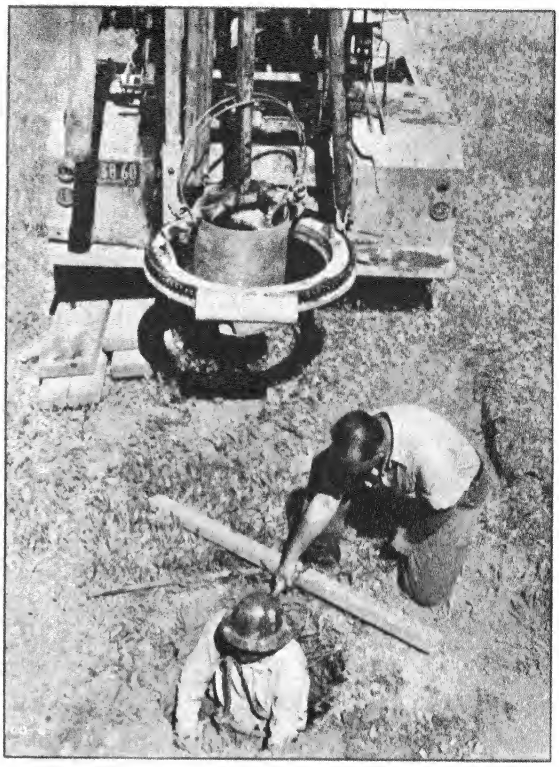
latch so that it can be opened for easy emptying of the barrel The bucket auger shown in Fig 56 and 57 has an outside diameter of 24 in , but by attaching a reamer it can drill holes up to 48 in in diameter The auger is operated by a combination drilling rig with a 30-in rotary table, drilling rigs of the type shown in Fig 37 and 38 can also be used The combination drilling rig, Fig 56 and 57, was developed by the Materials and Research Department, California Division of Highways, **Porter (162, 347).** In addition to the rotary table, the rig is provided with a spudding arm, winches, and pumps It can be used for percussion drilling, rotary drilling and core boring, auger boring, operation of drive samplers, dewatering of holes, and field permeability tests

Auger boring has the great advantage over wash boring, percussion, and ›tary drilling that the soil removed by the auger, although considerably disturbed,



CALIFORNIA DRILLING RIG

FIG 56



BUCKET AUGER AND ACCESSIBLE BORE HOLE

FIG 57

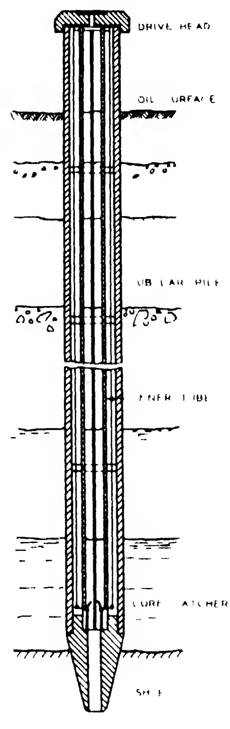
:nerally is suitable for positive identification The soil profile and depths at hich undisturbed samples should be taken can therefore be determined with greater :curacy by this method than with any of the previously described methods Since e bore hole is kept dry, auger boring is particularly well suited for advancing ›rings in partially saturated materials above the ground-water level, especially hen undisturbed samples are to be obtained of these materials Furthermore, :termination of the free ground-water level is also facilitated by auger boring ue to these advantages and the development of light and compact, motorized drill- ıg rigs, power-operated augers are being used on an increasing scale in foundation ‹plorations

.17 Continuous Sampling

Each sampling operation advances the bore hole, and the boring may be :complished entirely by sampling In this case the method becomes one of both ‹ploration and sampling and may be called continuous sampling and further desig- ıted by the particular method of sampling used.

Continuous sampling by means of core boring is nearly always used in exploration of rock. Borings in soil may also be advanced entirely by sampling when the bore hole is uncased and core barrels or piston samplers are used When these samplers and open drive samplers are used in cased bore holes, the sampler will produce a hole slightly smaller than that of the casing It is therefore necessary to clean the casing after advancing it to the bottom of the hole and before taking a new sample, the method is one of alternate sampling and cleaning Withdrawal of the sampler and separation of the sample from the subsoil will generally disturb the soil below the bottom of the bore hole When the primary purpose is to obtain undisturbed rather than fully continuous samples, it is therefore desirable to advance the hole a short distance -- say two to three times its diameter -- before taking a new sample A still greater advance may be required when withdrawal of the sampler causes caving of the bottom and lower part of the hole

A soil boring method which was developed by **Burkhardt** (307, 505) and called the "Pile Boring Method" may be classified as fully continuous sampling The method consists in driving a heavy steel pipe or tubular steel pipe into the ground, Fig 58 A split steel liner with a core catcher and trigger mechanism is held in firm contact with the shoe of the drive pipe. After advancing the pipe 6 to 7 ft, the liner is withdrawn with the soil sample, and an empty liner is then inserted and the driving resumed Borings have been extended to depths of about 130 ft in this manner and samples with a diameter of 21 cm obtained of sand, gravel and glacial till The method has been used only to a limited extent since it requires pipe with large diameter and thick walls and consequently very heavy driving equipment, and since the samples obtained usually are seriously disturbed by the heavy walls of the pipe and shoe and vibrations caused by the pounding of a heavy drop hammer



BURKHARDT PILE BORING METHOD

FIG 58

Continuous sampling in soils is generally slower and more expensive than intermittent sampling in combination with one of the previously described boring methods, but there are exceptions to this rule When modern rotary drilling rigs or power-driven augers are not available, continuous sampling may be used to advantage for advancing large-diameter borings in stiff and tough strata of clay and mixed soils, **Fehlmann** (521, 522). According to **Shannon** (171), the Boston District, Corps of Engineers, has made faster progress and reduced costs by use of continuous sampling in advancing 3-in. diameter borings through compact, gravelly glacial till, which is difficult to penetrate by any boring method A simple thick-walled sampler, similar to the one shown in Fig. 177, is used, and particularly tough strata are broken up by exploding one or two sticks of dynamite in the hole before each sampling operation

The greatest advantage of continuous or nearly continuous sampling is that

it provides more reliable and detailed information on soil conditions than any other method with the exception of accessible explorations Continuous sampling is therefore used extensively in detailed and special foundation explorations for important structures

2.18 Accessible Explorations

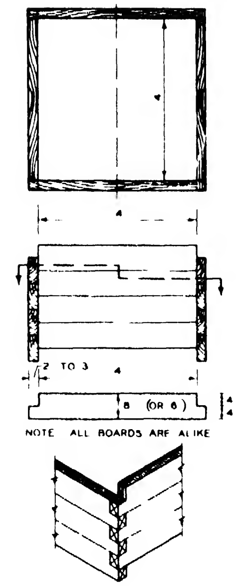
Accessible explorations are test pits, test trenches, caissons, borings, shafts, tunnels, and drifts large enough to permit entrance of a man and inspection and sampling of subsurface materials in situ The minimum dimensions are usually determined by the space required for efficient work rather than by accessibility.

Test pits.- Square or circular pits with a diameter of about 4 ft or unsheeted rectangular pits, 3 by 5 ft, are often used, however, a rectangular cross section of 4 by 6 ft permits easier and often cheaper excavation This rectangular section is also the minimum required when vertical sheeting is driven ahead of the excavation and large undisturbed samples are to be taken. The dimensions are net dimensions at the bottom of the pit and do not include the space required for sheeting, wales, and special arrangements for drainage. Starting dimensions at the ground surface may be much greater for deep test pits requiring several offsets or lifts

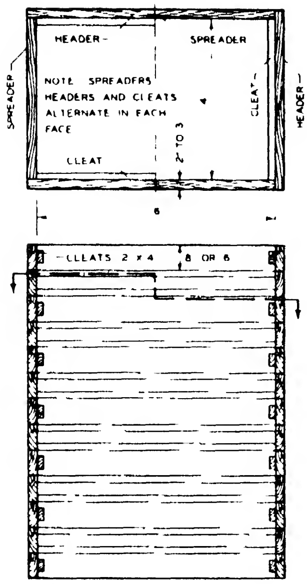
Test pits are generally excavated by hand, but a considerable saving in time and expense can often be effected by use of a clamshell or orange-peel bucket in excavating shallow, unsheeted test pits However, power equipment should be used only for rough excavation and not when approaching the depths at which undisturbed samples are to be taken.

Shallow test pits in fairly firm ground can generally be excavated without any support of the pit walls, but sheeting is required in unstable ground and for deep pits Arch action in the surrounding soil will materially decrease the earth pressure acting on the sheeting, at least when dimensions of the pit are small and when material displacements in the surrounding soil can be avoided during the excavation and the short period of actual use of the pit. The dimensions of the sheeting are in such cases based on practical experience rather than on theoretical earth pressures The dimensions shown in Fig 59 to 65 are adequate only under such favorable conditions, they must be increased when the pit is large, when the soil is soft and hydrostatic pressures are to be resisted, and when there is danger of soil movements on account of rough methods of excavation, vibrations, etc.

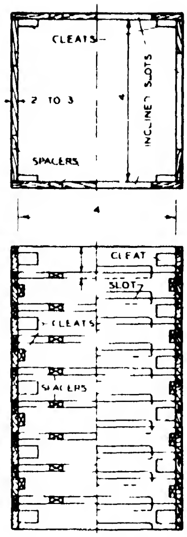
Horizontal or box sheeting is the simplest of all types of sheeting. It is easy to install, permits offsets when obstructions are encountered, and requires less excavation than other types for given net dimensions of the pit. In contrast to vertical sheeting driven ahead of the excavation, box sheeting permits inspection of the soil strata in the walls of the pit and is less likely to disturb the soil to be sampled. The boards are supported on each other either by notching -- Fig. 59 shows one of several methods of notching -- or by full end bearing on alternate boards and partial support



NOTCHED BOX SHEETING
FIG 59



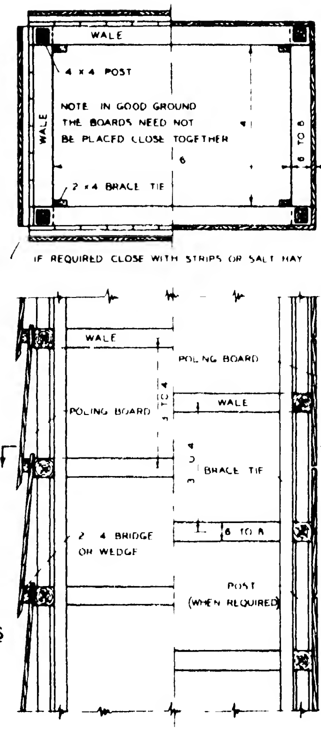
BOX SHEETING WITH CLEATS
FIG 60



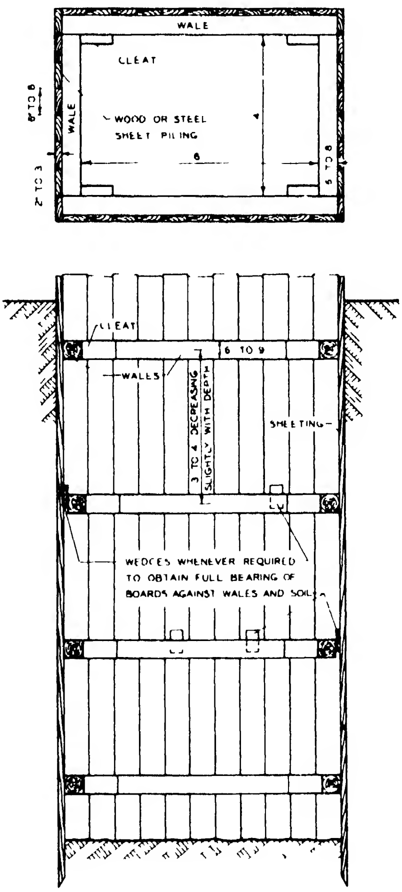
FRENTIS & WHITE UNDERPINNING 193 P 62

A - SPACERS B - SLOTS

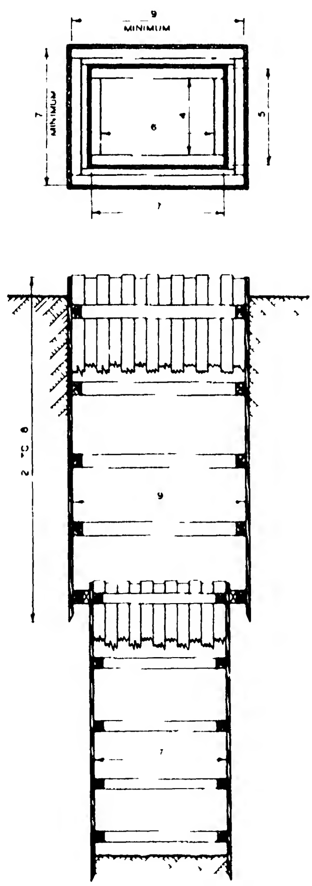
BOX SHEETING WITH LOUVERS
FIG 61



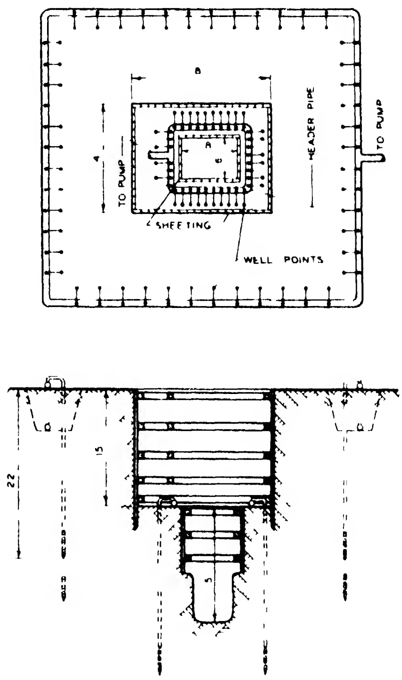
A-INCLINED BOARDS B-VERTICAL BOARDS
FIG 62 - POLING BOARDS



VERTICAL SHEETING - ONE LIFT
FIG 63



VERTICAL SHEETING - TWO LIFTS
FIG 64



F S BROWN JOUR BOSTON SOC CIV ENG APRIL 1941

TEST PIT AT FRANKLIN FALLS DAM
VERTICAL SHEETING - THREE LIFTS - WELL POINTS
FIG 65

NOTE THE DIMENSIONS OF SHEETING WALES ETC IN FIGS 59 TO 65 APPLY ONLY TO SMALL TEST PITS IN FAIRLY STABLE SOIL SEE TEXT

of the other boards by cleats, Fig 60 and 61 -- **Mohr (341), Prentiss and White (234).** Small openings or louvres between the boards, Fig 61, facilitate drainage and permit repacking the space behind the boards with soil or salt hay in case cavities are formed by soil movements or seepage Salt hay is less liable to rotting and better suited for packing than ordinary hay Notched sheeting or cribbing can also be installed with openings between the boards simply by making the depth of the notch smaller than half the width of the board Careful excavation and full and uniform contact between the soil and the boards are essential to avoid earth movements, which may increase the pressure on the sheeting, cause failure of the bottom of the pit, and disturb the soil to be sampled

It is difficult and often impossible to use box sheeting in very soft or loose soils Inclined poling boards, which are driven slightly ahead of the excavation, may then be used, Fig 62A. The inclined boards may be changed to vertical boards, Fig 62B, when firmer ground, permitting temporary unsheeted excavation, is encountered Steel liner plates, as used in tunneling, have recently been used successfully in test pits instead of poling boards of wood Poling boards and liner plates cannot be driven far ahead of the excavation and, although they can be used in soft soil and loose soil, they require somewhat firmer ground than true vertical sheeting On the other hand, they permit maintenance of the original dimensions of the pit, irrespective of its depth

Vertical sheeting may consist of plain boards, tongue and groove boards or steel sheet piling, Fig 63, and has the advantage that it can be driven far ahead of the excavation when required to prevent loss of ground in soft soils or loose, cohesionless soils In firm soils the sheeting is generally advanced more or less concurrently with the excavation. The pit may even be advanced a little ahead of the sheeting, but the excavation must then be very carefully performed to avoid cavities behind the sheeting Loose boards or sheet piles, also called runners, should be wedged to insure full bearing against both the bracing or wales and the soil. The length of runners which can be handled conveniently is limited, and an offset is generally required for every 12- to 18-ft advance in depth, Fig 64 and 65. In planning the starting dimensions of a pit with several lifts it must be taken into consideration that the sheeting of a lower lift should be at least 2 to 3 in inside the wales of the upper lift in order to facilitate the driving of the sheeting The vibrations caused by driving of the sheeting may disturb the soil to be sampled, especially when the sheeting is driven ahead of the excavation The samples should therefore be taken near the center of the pit and not closer than 12 in to the vertical sheeting

Various methods of sheeting may be used in a single deep test pit. Vertical sheeting may be required in penetrating soft strata near the ground surface, but poling boards or box sheeting may be adequate when firm strata are reached, and an offset and decrease in the dimensions of the pit can thereby be avoided A pit started in firm soil with box sheeting may be advanced through relatively soft soil by means of poling boards or liner plates

Extreme care must be taken in control of ground water, especially when a

pit is advanced through soils with little or no cohesion. Cohesionless soils should be under capillary pressure when undisturbed samples are to be taken, that is, the ground-water level in the central part of the pit should be depressed below the bottom elevation of the samples Pumping directly from a sump and drainage ditches in the pit may be used in cohesive soils or mixed and gravelly soils but in sand and silt only when the depth below the original ground-water level is slight Even then it may be necessary to maintain a layer of gravel in the drainage ditches and to protect the central part of the pit by sheet piling extending below the bottom of the ditches Dewatering by means of well points, Fig 65, is the safest method of control, and it should be used when pits in cohesionless soils are extended well below ground-water level

Test trenches.- The practical minimum bottom width of test trenches is 30 to 36 in , but a width of 24 in is occasionally used Trenching or ditching machines can often be used to advantage In comparison with test pits, test trenches have the advantage of providing a continuous or two-dimensional soil profile They are primarily used for very shallow explorations in soil requiring little or no support of the sides of the trench and especially when the depth to rock or strata of exceptional bearing capacity is very shallow

Caissons.- Cylindrical caissons with a steel or concrete shell are occasionally preferred instead of sheeted test pits when the caissons also can be used as a part of the proposed foundation structure The practical minimum bottom diameter is about 3 ft, but a diameter of 4 ft or more is generally used Caissons have the great advantage that water level can be controlled by means of compressed air in the caisson This method is generally the most practical and often the only one by means of which deposits of very pervious, cohesionless soils deep below ground-water level can be examined in situ When undisturbed samples of such soils are to be obtained, the air pressure in the caisson should be greater than the hydrostatic pressure so that capillary forces will be called into action and produce an apparent cohesion

Accessible borings.- A boring with a diameter of 24 in is accessible, but a diameter of about 36 in is preferable, and bore holes up to 6 ft in diameter have been drilled for special field tests Accessible borings in soil and very soft rock are drilled with power-operated augers of various types, some of which were described in Section 2 16 Other types, specially designed for pre-excavation for piles and shaft piers (219, 614), are also used Shot core barrels and steel-toothed, single tube core barrels are used in rock or frozen soils (321, 348, 537, 948), see Sections 13.2 and 13.4.

When modern drilling rigs and core barrels are used, accessible borings can often be made in a fraction of the time and cost required for sinking test pits in soil and shafts in rock by hand methods. A rate of progress of 25 ft per hr has been attained in soil under favorable conditions. The borings are uncased and dry and therefore require fairly stable soil conditions However, many soils remain stable

for the short period required to complete the boring and inspection and sampling of the soil strata, whereas a slowly advanced test pit in the same soil may require sheeting The method has also been used successfully in unstable soils by first freezing the soil around and below the bore hole (911), Fig 252 Accessible borings in soil have been extended to a depth of 120 ft and in rock up to 150 ft By use of rodless core boring, in which the rotative power unit is suspended immediately above the core barrel, mine shafts have been sunk to depths of over 1000 ft

Tunnels and drifts.- Exploratory tunnels and drifts are primarily used in the final exploration of dam sites The economical minimum dimensions are 3 5 by 6 5 ft or 4 by 6 ft

Advantages and limitations.- Of all methods, accessible explorations provide the most reliable and detailed information on soil and rock conditions along a specific vertical, inclined, or horizontal line They make it possible to examine, sample, and perform special field tests on the material in situ Furthermore, the very act of advancing such an exploration gives valuable information on the difficulties to be encountered in and the probable costs of excavation for the proposed structure

Larger and usually less disturbed samples can be obtained in accessible explorations than in bore holes of relatively small diameter, but certain causes of disturbance should be recognized and proper measures taken to ascertain and reduce their influence on the condition of the samples obtained Stress changes in the soil below the bottom of an ordinary bore hole can be reduced by filling the hole with water or drilling fluid, but accessible explorations must be kept dry, and there is therefore greater danger that a slow plastic flow and consequent disturbance of the soil may occur in the vicinity of the bottom of a deep test pit or accessible boring or the face of a tunnel This danger is, of course, decreased when a tunnel or caisson is advanced under compressed air

Unless soil is very stable, the extent and rate of soil displacements should be investigated so that it can be determined if the soil to be sampled already has been partially disturbed, and so that the samples may be taken where there is a minimum of disturbance. Observations of the movements of soil surface will indicate displacements, but more reliable results are obtained by "squeeze measurements" in which the movements of a rod or spearhead, driven into the soil ahead of the excavation, are observed -- **Terzaghi (973), Peck (620).** Loss of ground, or the difference between the volume of the excavated material and the volume of the pit or tunnel, will also give an indication of plastic movements, but this difference is difficult to determine with satisfactory accuracy

The soil may also be disturbed by swelling, caused by stress reduction, migration of water from the surrounding soil, and expansion of gas and air in the soil, see Section 5.9. Exposure to air may cause oxidation and, combined with the effect of stress changes and contact with free water, complete disintegration of certain partially cemented soils and soft rocks However, these processes, as well

as loss of water by evaporation, take place over a period of time, and it is therefore essential that samples be taken as soon as possible after the rough advance and immediately after the final trimming and preparations for sampling

With favorable soil conditions and depending upon available equipment, shallow test pits and trenches and large-diameter borings may in some cases be used to advantage instead of ordinary borings, but accessible explorations are generally considerably more expensive than other methods of subsurface exploration. The results of reconnaissance and detailed explorations should be available before expensive accessible explorations are undertaken, not only to establish the need of such explorations but also to make it possible to determine the proper location, type, depth, dimensions, methods of excavation and control of water, etc

CHAPTER 3
GROUND-WATER OBSERVATIONS

3.1 General

A detailed ground-water survey, involving determination of the free ground-water level or levels, hydrostatic pressures in various strata, flow, yield, quality, sources, etc , requires considerable time and often special methods and equipment. In common foundation explorations it is usually sufficient but also very essential to determine the free ground-water levels and conspicuous excess hydrostatic pressures in pervious strata Furthermore, a subcommittee of the Committee on Earth Dams, Am Soc Civ Eng , has been appointed to study and develop methods for determination of pore-water pressures in soils A detailed description of special methods and equipment for this purpose is therefore considered outside the scope of this report, and the following review is limited to general principles and to observations which can be made with simple, standard equipment and without serious interruption of boring and sampling operations

3.2 Ground-Water Levels and Pressures

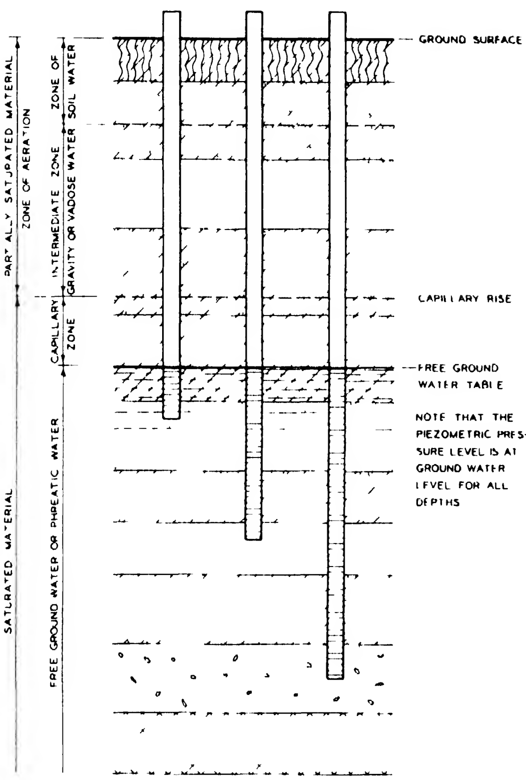
A free ground-water table or level is defined as the contact surface between the free ground water and the capillary zone, Fig 66, that is, the level ultimately assumed by the water in a hole extended a short distance below the capillary zone Ground-water conditions may be called regular when there is only one free ground-water surface, and when the hydrostatic pressure increases linearly with depth, as in an open body of water, that is, the piezometric pressure level is the same as the free ground-water level at any depth below the latter

In making ground-water observations, it must constantly be borne in mind that regular ground-water conditions as defined above are not always the normal conditions and that irregular conditions, Fig. 67, often are encountered In some localities there may be one or more isolated bodies of water or perched ground-water tables above the main ground-water table. The formation of perched ground-water tables is caused by impervious strata which prevent the water from seeping down to the main body of ground water

Hydrostatic pressure does not always increase uniformly with the depth below the main ground-water table Subnormal pressures, or piezometric pressure levels below the main ground-water level, may be caused by downward seepage to more porous and better drained strata. They may also be caused, temporarily, by

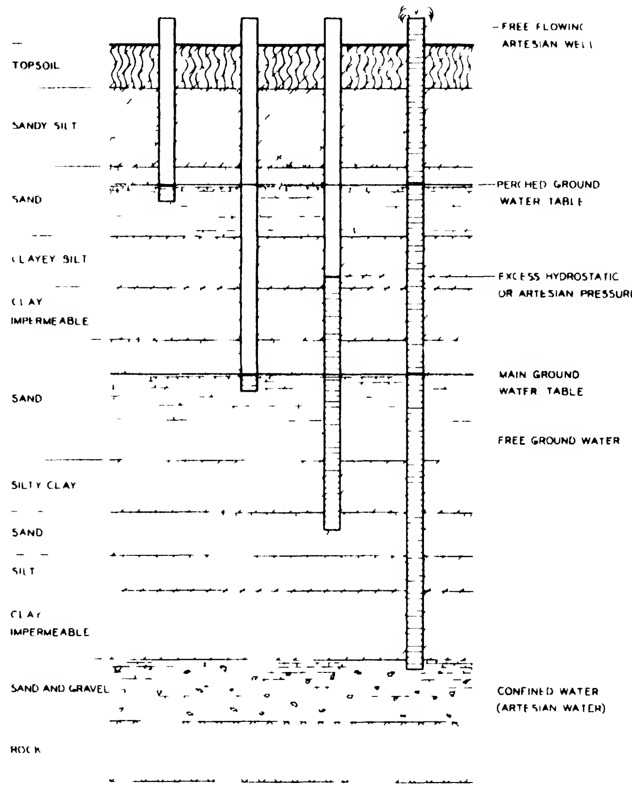
a decrease of the stresses in the soil below the main ground-water table

Water is said to be under excess hydrostatic pressure when the piezometric pressure level is above the main ground-water level. Such a pressure is also called



REGULAR GROUND WATER CONDITIONS

FIG 66



IRREGULAR GROUND WATER CONDITIONS

FIG 67

"artesian pressure", and a well drilled to strata with excess hydrostatic pressure is called an artesian well The term artesian is sometimes, popularly but erroneously, interpreted to mean that the piezometric pressure level rises above the ground surface. A well drilled to strata with water having a piezometric pressure level above the ground surface is called a free-flowing artesian well Artesian pressures may be found in strata which are confined between impervious strata and are connected to a source of water at higher elevation Temporary excess pressures may also be caused by an increase of the stresses in the soil

The ground-water levels and pressures may be subject not only to seasonal but also to diurnal changes. These changes are caused by precipitation, evaporation, seepage, pumping, and the water levels in nearby rivers, lakes, estuaries, and the sea The influence of tidal changes may be observed at distances up to several miles from rivers and estuaries, the range depending upon the topographical and geological conditions. Atmospheric or barometric pressure changes may also cause minor changes in ground-water levels and pressures It is therefore important that not only the day but in some cases also the exact time of ground-water observations be

noted in the exploration records, the water levels in nearby open bodies of water should also be recorded

It is seldom necessary to make detailed ground-water observations in each one of a group of closely spaced bore holes, but sufficient observations should be made to establish the general shape of the ground-water table, and it is important that observations be made in the first boring of a group When observations are made later, ground-water levels and pressures in strata with different piezometric pressure levels may be changed by seepage through the already completed bore holes, unless these holes are carefully backfilled

3.3 Time-Lag in Ground-Water Observations

During normal boring operations, the water level in the bore hole will seldom correspond to the hydrostatic pressure in the surrounding soil, and water will then flow into or out of the hole Reliable determination of ground-water levels and pressures requires that the hydrostatic pressures in the bore hole and in the soil be equalized and that the water in the holes reaches a stable level The time required for this equalization is the time-lag

When the void ratio and water content of the soil in the vicinity of the hole or its bottom remain constant, the total flow or volume of water required to equalize the difference in hydrostatic pressures in the soil and the hole depends only on the dimensions of the hole or pressure measuring device and on the hydrostatic pressure difference The corresponding time-lag may be called the hydrostatic time-lag

The stress conditions in the soil near the bottom of the hole are changed by advance of the hole, installation of pressure measuring devices, and by a flow of water to or from the hole A permanent and/or transient change in water content of the affected soil will then take place, and the time required for the corresponding volume of water to flow to or from the soil may be called the stress adjustment time-lag This time-lag affects primarily observations made immediately after advance of the bore hole or installation of pressure measuring devices, and it is difficult to evaluate The stress adjustment time-lag is insignificant in fairly pervious and incompressible, fully saturated soils, but it may increase or decrease the total time-lag to a considerable extent when the soil is compressible and relatively impervious, and when it contains air and other gases in the pores or dissolved in the pore water

The time required for complete equalization of hydrostatic pressure differences is theoretically infinite, but practical equalization may be considered attained when the difference in pressure has been reduced to a certain definite, small value, or when 90 to 99 percent of the original pressure difference has been eliminated The practical hydrostatic time-lag depends on· (1) the diameter of the bore hole or the type and dimensions of the pressure measuring device, (2) the intake area or the depth of the bore hole below ground-water level or below the edge of the casing, and (3) the permeability of the soil The time-lag also depends on the original pressure

difference when this difference must be reduced to a definite value, but is independent thereof when the allowable, final pressure difference is defined as a percentage of the original difference To illustrate the order of magnitude of the practical hydrostatic time-lag, the times required for 90 percent equalization of the original pressure difference have been computed by the writer for various borings, intake areas, pressure measuring devices, and are shown in Table 4 The computations are based on

TABLE 4 - APPROXIMATE HYDROSTATIC TIME-LAGS FOR 90 PERCENT EQUALIZATION

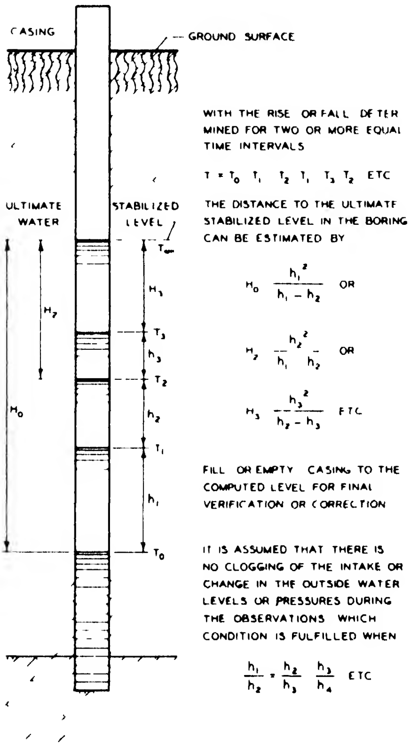
	Approximate Soil Type	SAND			SILT			CLAY			
	Coefficient of Permeability in cm/sec	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}	10^{-10}
1	2 Casing Soil in Casing 1 3D - 6	6^m	1^h	10^h	4.2^d						
2	2 Casing Soil Flush Bottom Casing	0.6^m	6^m	1^h	10^h	[illegible]^d					
3	2 Casing Hole Extended L - 3D 6		1.5^m	15^m	2.5^h	25^h	10^d				
4	2 Casing Hole Extended L 12D - 24			6^m	1^h	10^h	4.2^d	42^d			
5	3/8 Piezometer with Well Point Diameter 1 Length 18				3^m	30^m	5^h	50^h	21^d		
6	3/8 Piezometer with Well Point and Sand Filter D 6 L 36					12^m	2^h	20^h	8.3^d	83^d	
7	1/16 Mercury Manometer Single Tube Porous Cup Point D 1-1/4 L 2-1/2		One-half of values for 1/16 Mercury U Tube Manometer or 4-1/2 Bourdon Gage				2^m	20^m	3.3^h	33^h	14^d
8	1/16 Mercury Manometer Single Tube with Well Point D 1.5 L - 18							6^m	1^h	10^h	[illegible]2^d
9	3 W E S Hydrostatic Pressure Cell Direct Contact with Soil								16^m	6^h	[illegible]^h
10	3 W E S Hydrostatic Pressure Cell Sand Filter D 6 L 21									14^m	2.3^h

Symbols m minute h hours d day Assumptions Isotropic permeability no air in system no clogging secondary or stress adjustment time-lag negligible All Cases Time-lag inversely proportional to permeability 70% equalization at half and 99% equalization at double the times required for 90% equalization Cases 1 to 4 The time-lag increases linearly with the diameter provided the value of L/D are not changed Cases 7 and 8 According to tests by A Warlam the volume change of a 4-1/2 Bourdon Gage [illegible] 0.5 to 1.0 cm^3 for 1 kg/cm change in pressure or roughly one half of that for a 1/16 single tube mercury manometer Case 9 and 10 Refer to hydrostatic pressure cell by the Waterways Experiment Station in Vicksburg diameter of diaphragm 3.5 deflection of diaphragm 0.008 for 60 lb/sq in The computed time-lag have been rounded off to convenient values

the assumptions that the soil is uniform and has isotropic permeability, that there is no air or gas in the system and no clogging of the intake area, and that the actual ground-water level or pressure remains constant during the equalization The influence of the stress adjustment time-lag is not included in the values given in the table

The practical time-lag may be reduced materially by progressively emptying or filling the bore hole with water until a falling water level changes to a rising level, or vice versa By observing the decreasing rate of fall or rise of the water level, it is also possible to estimate roughly the depth to the ultimate stabilized level, provided the influence of the stress adjustment time-lag is not too great As shown in Fig 68, the computations are very simple when the observations are made at equal time intervals. Even when the practical time-lag is reduced by such methods, considerable time and special equipment are required for accurate determination of ground-water levels and pressures in relatively impervious soils Therefore,

ground-water observations during normal boring operations are generally confined to fairly pervious soils and strata



$$H_0 = \frac{h_1^2}{h_1 - h_2} \quad \text{OR}$$

$$H_2 = \frac{h_2^2}{h_1 - h_2} \quad \text{OR}$$

$$H_3 = \frac{h_3^2}{h_2 - h_3} \quad \text{ETC}$$

$$\frac{h_1}{h_2} = \frac{h_2}{h_3} = \frac{h_3}{h_4} \quad \text{ETC}$$

ESTIMATING THE PIEZOMETRIC PRESSURE LEVEL
FIG 68

3.4 Observation of Loss or Gain of Water

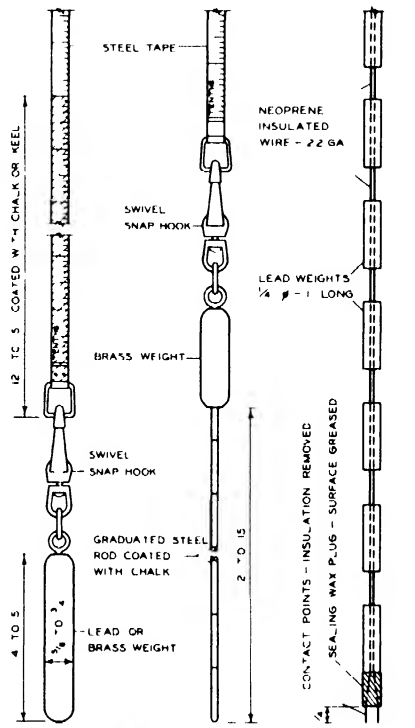
As indicated above, determination of ground-water levels and pressures in a simple bore hole causes serious interruption of the boring operations unless fairly pervious strata are encountered Such strata can be recognized in part by the character of the cuttings and samples, and in part by a fall or rise of the water level in the bore hole or in the sump or main mud pit A loss of water indicates pervious strata or cavities in rock A rise or gain indicates not only pervious strata but also the presence of water with a pressure greater than that corresponding to the current water level in the bore hole

When pervious, water-bearing strata are encountered, it is desirable to clean out the bore hole and determine the stabilized water level as discussed in the following sections When the boring schedule does not permit interruption of operations for a sufficient length of time, the depth of the hole at the time of conspicuous loss or gain of water should be noted in the boring record It is also desirable to record the water level or pressure in the hole and the rate of its rise or fall, since these data may serve as a basis for a rough estimate of the stabilized level and of the permeability of the strata

3.5 Measurement of Depth to Water Surface

The depth to the water level in a bore hole may be determined by means of a float attached to a measuring tape The float may consist of wood with a waterproof coating or of a hollow metal cylinder The float must be sufficiently heavy to cause a distinct change in the pull on the measuring tape when the float is buoyed-up by the water. A correction must be made for the temporary rise of the water level caused by displacement of water by the float This method is satisfactory for rough measurements, but the tension in the tape is decreased gradually, and it is difficult to determine accurately the degree of submergence or the depth at which the entire weight of the float is carried by the water. Some floats are therefore equipped with a whistle which is sounded by air forced out of the lower part of the float when it is submerged in water Greater accuracy is obtained with a float consisting of an outer shell in which the actual float slides and closes an electrical circuit after it has been moved upwards a short distance.

Simpler than a float with electrical indication of contact with water, and more accurate than an ordinary float, is the wetted tape or rod method A small lead weight is attached to the measuring tape, the lower part of which is coated with chalk or keel, Fig 69A The weight is lowered into the water until a part of the chalked section of the tape is submerged After withdrawal the wetting line on the tape can easily be read to a fraction of an inch and the corresponding depth to the water surface computed Depending upon the diameter of the bore hole and the accuracy desired, a small correction may have to be made for the water displaced by the weight This correction can be eliminated by attaching a thin graduated rod to the weight, Fig 69B, and lowering the rod but not the weight into the water Furthermore, the chalk or keel will adhere better to the unfinished surface of the rod than to the highly polished surface of a steel tape. The wetted tape or rod method also has the advantage that it can be used in borings and standpipes of very small diameter, but it has the disadvantage that the approximate depth to the water surface must be known in order to get a wetting line on the chalked part of the tape or rod



A-CHALKED TAPE B-CHALKED ROD C-ELEC CONTACT

WATER SURFACE DEPTH GAGES

FIG 69

The above mentioned disadvantage of the wetted tape or rod method can be eliminated by providing the weight with electrical indication of contact with the water surface. Such an electrical depth gage, developed by **A. Casagrande** (105) and especially designed for use in standpipes and piezometers of small diameter, is shown in Fig 69C The measuring tape is replaced with two insulated wires with tape markings for measurement of depth The lead weight is divided into short sections to prevent wedging in the pipe The contact point is formed by removing the insulation from the ends of the wires and spacing them about 1/4 in apart by a plug of sealing wax. The wax plug and the lower weight sections are covered with grease to prevent adhesion of water when repeat measurements are made. The wires are connected to a small battery and ohmmeter. This depth gage has been used successfully in piezometers with an internal diameter of only 3/8 in.

3.6 Determination of the Free Ground-Water Level

The depths to free ground-water levels, whether perched or main levels, should preferably be determined as soon as it is estimated that such levels have been reached. Further extension of the boring may lead to erroneous results, since impervious strata below a perched body of ground water may be penetrated, or strata

with artesian pressures may be reached The depth to free water is most easily determined when the boring is kept dry while being advanced through the overlying, partially saturated or capillary zone Entrance of water into the hole can then be observed, and the danger of extending the hole too far below the free water table is reduced

Casing is generally used when the boring is advanced with water in the hole At the estimated free ground-water level, or when the first pervious stratum below this level is encountered, the hole should be extended a short distance below the edge of the casing, if this is possible without causing caving The hole should then be thoroughly cleaned and washed until the water is clear in order to avoid increasing the time-lag by sedimentation and formation of a filter skin The hole is then emptied to the estimated free water level, and the movement of the free water surface observed until a sufficiently close estimate of the stabilized level can be made

When the boring is filled with drilling fluid, both the sides and bottom of the hole will be sealed with the "mudcake", which will be broken only when cavities in rock, clean coarse gravel, or pervious strata with strong artesian pressures are encountered. The approximate location of the free ground-water level must then be estimated by the character of the cuttings and samples or on the basis of the general stratigraphy of the area When pervious strata below the estimated water level are reached, the drilling fluid should be replaced with clean water, the bore hole extended a short distance below the sealed bottom, thoroughly cleaned, and then emptied to the estimated ground-water level The replacement of drilling fluid with water may cause caving of the hole, in which case casing will be required for a reliable determination of the ground-water level

The procedure in determining the free ground-water level in strata below a perched ground-water table is the same as described above, but a cased bore hole will then be required, since seepage from the perched body of water would raise the stabilized water level in an uncased bore hole extended to a lower ground-water table

3.7 Determination of Hydrostatic Pressures

A reliable determination of excess or subnormal hydrostatic pressures in strata below the free ground-water level requires a cased bore hole, since the stabilized water level in an uncased hole would be influenced by leakage to or from the overlying strata. The procedure is otherwise the same as in determining the depth to the free ground-water level, that is, the hole should be extended a short distance below the casing, cleaned out, and filled with clean water to the estimated piezometric level, whereupon stabilization is awaited before making the final depth measurements

When free-flowing artesian strata are encountered but the piezometric level is only slightly above the ground surface, it may be determined by adding one or two sections to the casing If the pressure is great, it may be necessary to close the top of the casing and attach a manometer. An air outlet valve should then also be

provided in order to prevent accumulation of air and other gases in the upper part of the casing

There is danger, even in a cased bore hole, that the stabilized water level will not indicate accurately the hydrostatic pressure in the soil at the bottom of the hole, and that this level may be influenced by leakage along the casing and through the joints of the casing. The influence of such a leakage is generally small when the work is carefully executed and the soil is so permeable that the practical time-lag does not exceed a few hours, but the danger that the results may be influenced seriously by leakage increases rapidly with the time-lag and decreasing permeability of the soil.

Knowledge of pore-water pressures in relatively impervious soils is assuming increasing importance with the progress in soil testing and methods of design of important foundation and earth structures, but these pressures cannot be determined with satisfactory accuracy during normal boring operations on account of the time-lag and the danger of leakage. Carefully installed observation wells, small-diameter piezometers, or hydrostatic pressure cells must then be used

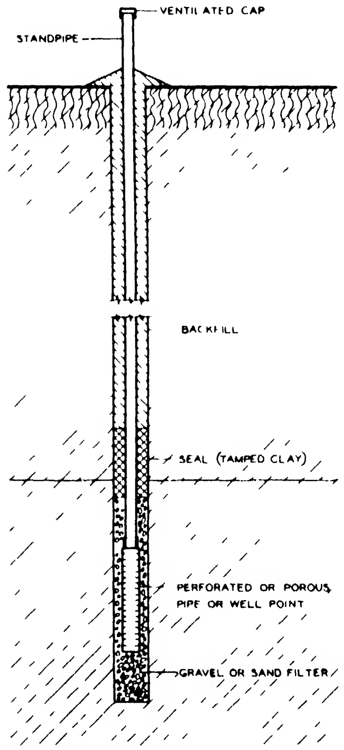
3.8 Observation Wells

Casing is often left in the bore hole when it is desired to continue ground-water observations over a period of time or when the ground-water levels and pressures in relatively impervious soils are to be determined The casing joints should be tightly made up and, if necessary, sealed with wicks and pipe dope The casing should fit tightly in the bore hole to decrease outside leakage, therefore, the diameter of the casing shoe should not be larger than that of the casing proper The bore hole should be advanced a couple of feet below the casing or the casing withdrawn a similar distance If there is danger of caving of the uncased part of the hole, it may be filled with well graded gravel The hole should be carefully cleaned both before and after being filled with gravel, and the water left in the hole should not contain any suspended matter The casing should extend a sufficient distance above the ground surface and also be provided with a ventilated cover to prevent entrance of surface water, rain, and dirt Even with these precautions there is danger of ultimate clogging of the gravel or formation of a filter skin, and the method is therefore not suitable for protracted observations of rapidly fluctuating ground-water levels and pressures.

A standard well point and pipe, driven or jetted into the ground, is often used as an observation well when the soil is relatively porous and ground-water conditions are fairly regular

For protracted and detailed observations, especially in the less permeable soils and with irregular or rapidly changing ground-water levels and pressures, it is preferable to use a specially installed observation well, an example of which is shown in Fig 70 A well point or section of porous concrete or sintered pipe is

attached to the lower end of the standpipe and is surrounded by a filter of well graded gravel or sand The hole must be carefully cleaned and filled with clear water before the standpipe with its porous point and filter are installed Extreme care must be taken in obtaining tight joints in the standpipe, and jointless tubing should preferably be used when the diameter is small The diameter of the standpipe should be as small as possible in order to decrease the time-lag A diameter of 4 to 6 in may be required when special floats and recording depth gages are to be used, but a diameter of 1 to 2 in. is sufficient for insertion of a wetted tape or rod gage, and the depth gage shown in Fig 69C can be used in tubing with an internal diameter of 3/8 in. The internal diameter should not be smaller than 3/8 in , since bubbles of air or other gases then may be retained in the standpipe instead of rising to the surface, and since it then becomes difficult to clean the tubing and the porous point should this become necessary after the installation is completed



OBSERVATION WELL OR PIEZOMETER
FIG 70

The annular space around the standpipe must be carefully backfilled and the lower part adequately sealed as the casing is withdrawn The seal should be located in or extended to impervious strata The casing may also be left in the ground, and the seal between the casing and a small-diameter standpipe may then be confined to the lower part of the casing and backfilling omitted. The seal may consist of compacted clay or bentonite or a mixture of the two materials. Bentonite provides the tighter seal, but there is danger that its great tendency to swelling may cause changes of stresses and pore-water pressures in the surrounding soil The effect of this swelling may be reduced by placing intermediate layers of sand or concrete in the seal.

An excellent piezometer, developed by **A. Casagrande (105),** consists of 1/2-in O.D. Saran tubing, which is connected to a porous point of sintered, non-metallic material by means of a Neoprene rubber bushing. The elimination of metals decreases the danger of electrolysis and development of gases The entire assembly is filled with water before installation by immersing the porous point a few feet in the water filled bore hole and connecting the free end of the tubing to a vacuum tank The seal is placed by rolling the clay or bentonite into small balls, which are dropped into the boring to form 3- to 4-in thick layers around the tubing, and each layer as well as intermediate sand layers is compacted by means of an annular tamper.

As will be seen in Table 4, when the intake or porous point is placed in clay, there is considerable time-lag even when the diameter of the standpipe is only 3/8 in. When the piezometric pressure level is near or above the ground surface, the standpipe

can be connected to a manometer or Bourdon gage and the time-lag greatly decreased thereby, but hydrostatic pressure cells are required when the pressure level is appreciably below the ground surface and rapidly changing pore-water pressures in clay are to be determined

3.9 Yield and Permeability

The approximate yield of water can be determined by bailing or pumping and observing the corresponding stabilized draw-down level in the bore hole However, the yield of a single, small-diameter boring does not always give a reliable indication of the pumping requirements for a proposed foundation pit, and better results are obtained by means of a caisson or test pit

A very rough estimate of the average permeability of the material around the bottom of a cased bore hole may be obtained by lowering or raising the water level in the casing and observing the rise or fall of the level as a function of time and with respect to the stabilized piezometric water level The depth of the bore hole below the casing, or the amount of soil in the casing, should be carefully determined, and the bore hole should be thoroughly washed with clean water before such experiments are undertaken The permeability determined by means of a single bore hole is primarily governed by the permeability of the soil in the immediate vicinity of the bottom of the hole, and results of permeability determinations are often subject to serious errors on account of local geological irregularities, disturbance of the soil caused by boring, sedimentation, internal erosion, and difficulties in determining the effective intake area The average permeability of a deposit is best determined by large-scale pumping tests, in which a given flow is maintained until the draw-down has become stabilized, and in which the corresponding water levels in the soil are determined by several auxiliary borings or observation wells

3.10 Sampling of Ground Water

Samples of ground water, intended for laboratory analysis, must be uncontaminated by foreign substances Such samples are easily obtained from borings into free-flowing artesian strata or when pumping tests are performed In other cases the bore hole must be thoroughly cleaned and completely emptied of the water or drilling fluid used in advancing the boring When the ground water has risen to a sufficient depth in the hole, a sample may be obtained by means of a thoroughly cleaned bailer.

The quantity of water required for a chemical and bacteriological analysis varies with the laboratory technique. A common requirement is one liter or quart, but some laboratory techniques require up to one gallon. Therefore, unless the requirements of the laboratory in which the water is to be analyzed are definitely known, it is advisable to take a one-gallon sample, which should be preserved in a thoroughly cleaned and sterilized glass container, adequately sealed and packed for shipment.

TABLE 5 - METHODS OF SAMPLING SUBSURFACE MATERIALS

GROUP	TYPE OR PURPOSE		SAMPLER OR METHOD		ID BORING OD SAMPLER In	SAMPLE DIAMETER In	MATERIALS IN WHICH USED	CONDITION OF SAMPLES
EXPLORATION	Clean-out Tools		Bailers		2 9 - up	-	Very soft soils loose cohesionless soils and slurry of all materials	Often non-representative with soil constituents mixed and segregated
			Sandpumps		2 0 - up	-		
	Slit Samplers		Longitudinal Slit		1 3 - 4 0	-	Soft soils silt and loose sand	Representative of average conditions but adjacent strata are often mixed
			Circumferential Slit or Cup		2 3 - - -	-		
	Augers		Helical or Worm Type Augers		1 5 - 16	-	Medium soft to stiff cohesive soils Partially saturated sand and silt	Seriously disturbed and often partially mixed but generally representative of the average condition
			Iwan or Post Hole Augers		4 - 9	-		
			Barrel Augers Helical or Iwan		2 5 - 5 6	-	All soils including gravelly soils	
			Disk and Bucket Power Augers		12 - 40	-		
DRIVE SAMPLING	Open Drive Samplers		Thick-Wall Solid-Barrel		1 4 - 8 0	1 0 - 7 0	All soils except coarse gravel Retainers req d in soft or loose soils	Top often non-representative rest part disturbed but representative
			Thick-Wall Split-Barrel		2 0 - 5 6	1 4 - 5 0		
			Thin-Wall Samplers		1 0 - 8 0	0 94 - 7 8	Thick-wall samplers as above Thin-wall Soft to stiff and loose to medium dense soils Special methods to prevent loss required in some soils	Representative to undisturbed depending on type of soil and design and method of operation of sampler
			Composite Samplers - Liners		1 3 - 8 0	0 94 - 7 0		
	Piston Samplers		Thin-Wall or Composite	Retracted Piston	7 8 - 6 0	3 4 - 4 9		
				Free Piston	3/4 - 6 0	5/8 - 5 9		As above less disturbance and danger of loss better recovery data
				Stationary Piston **	3/4 - 6 0	5 8 - 5 9	As above but incl very soft soils	
CORE BORING	Rotary Core Barrels	Soil Core Barrel	Hard-Metal Teeth Flush or protruding inner tube with liner		3 8 - 8 9	2 8 - 7 4	Stiff to hard clays brittle soils dense sand partial cemented soils	Probably less disturbance than by drive sampling Method in develop
		Shot Core Boring	Chilled steel shot in soft steel bit Single tube with calyx		2 8* - 4 8 36 - up*	5* - 3 4 34 - up*	All except very soft fissured or cavernous rock slow in hard rock	Cores of sound rock generally undisturbed but cores of non-uniform rock are often broken and soft and erodible sections ground up and removed by the circulating fluid unless special precautions are taken
		Diamond Bit	Single tube or double tube barrel with retracted inner tube		1 5* - 1 9 3 0 - up*	7/8* - 1 1 2 1 - up*	All sound rock but best suited for small cores of medium to hard rock	
		Hard-Metal Teeth	Tungsten Carbide Surface or Inserts	Single Tube	2 5 - 38	2 0 - 36	Soft to medium rock and frozen soil occasionally hard and dense soils	
				Double Tube	2 5 - 8 9	1 8 - 7 4		
		Hard-Metal Bit Oilfield Core Barrels	Standard stationary inner tube		3 9 - 12	1 2 - 5 5	Bladed Bit Hard soils or soft rock Roller or Cone Bit Hard formations	
			Wire-Line retractable inner tube		5 4 - 8 0	1 0 - 2 5		
			Pressure inner tube with valves		6 25	1 5 - 1 7	Developed for sampling of oil sands	Fluid and gas pressure maintained
	Percussion Core Boring Cable-Tool Core Barrel		Double Tube Sliding outer barrel with hard-surfaced steel bit		3 8 - 7 3	1 6 - 3 8	Medium soft to medium hard rock	Fair recovery but the cores are often broken into small sections
Side Wall Samplers			Open Drive Samplers Operation hydraulic wire-line or shooting		Bore Hole 4 8 - 8 5	7/16 - 1 - 1 4	Stiff and compact soils to soft or medium rock side walls of borings	Partially disturbed to undisturbed depending on formation and design
Surface Sampling in Accessible Explorations Earth Structures			Bag Sample Field Density Tests		4 - 10	-	Primarily sandy and gravelly soils	Representative but natural density
			Short Open Drive Samplers		2 - 6	1 9 - 5 9	Soft to medium stiff clavey soils loose sand and silt Control tests	As below but occasionally some disturbance and especially compaction
			Short Piston Samplers		3/4 - 6	5 8 - 5 9		
			Sampling by Advance Trimming		-	4 - 8	Stiff brittle or dense soils Compacted or partially saturated soils	Undisturbed excepting influence of stress changes and soil movements before or exposure during sampling
			Auger Core Barrels		6 3 - 6 5	3 7 - 4 0		
			Block or Box Sampling		-	8 - 12	Coarse dense brittle to hard soil	
Submarine Bottom Explorations			Scrapers and Clamshell Buckets		-	-	Only materials from bottom surface	Disturbed except the larger chunks
			Restricted Gravity	Composite Open Drive Samplers	1 8 - 3 3	1 0 - 2 4	All soils to soft rock Samples of hard and gravelly soils short but of very soft soils up to 18 ft long	Often partially disturbed depending on the character of the material and the design of the sampler
			Free-Fall Gravity					
			Driven by Shooting					
			Free-Fall Piston Sampler		3 5 - 3 7	1 8	As above but sample length to 50 ft	Some disturbance In development

The dimensions shown are approximate and represent the commonly used range Lower and upper limits marked * are rarely used in explorations for civil engineering purposes ** A drive sampler with liner and steel foils attached to a stationary piston, recently developed by the Swedish Geotechnical Institute permits taking 20 m long samples of soft soils in a single operation

CHAPTER 4
SAMPLING METHODS AND REQUIREMENTS

4.1 General

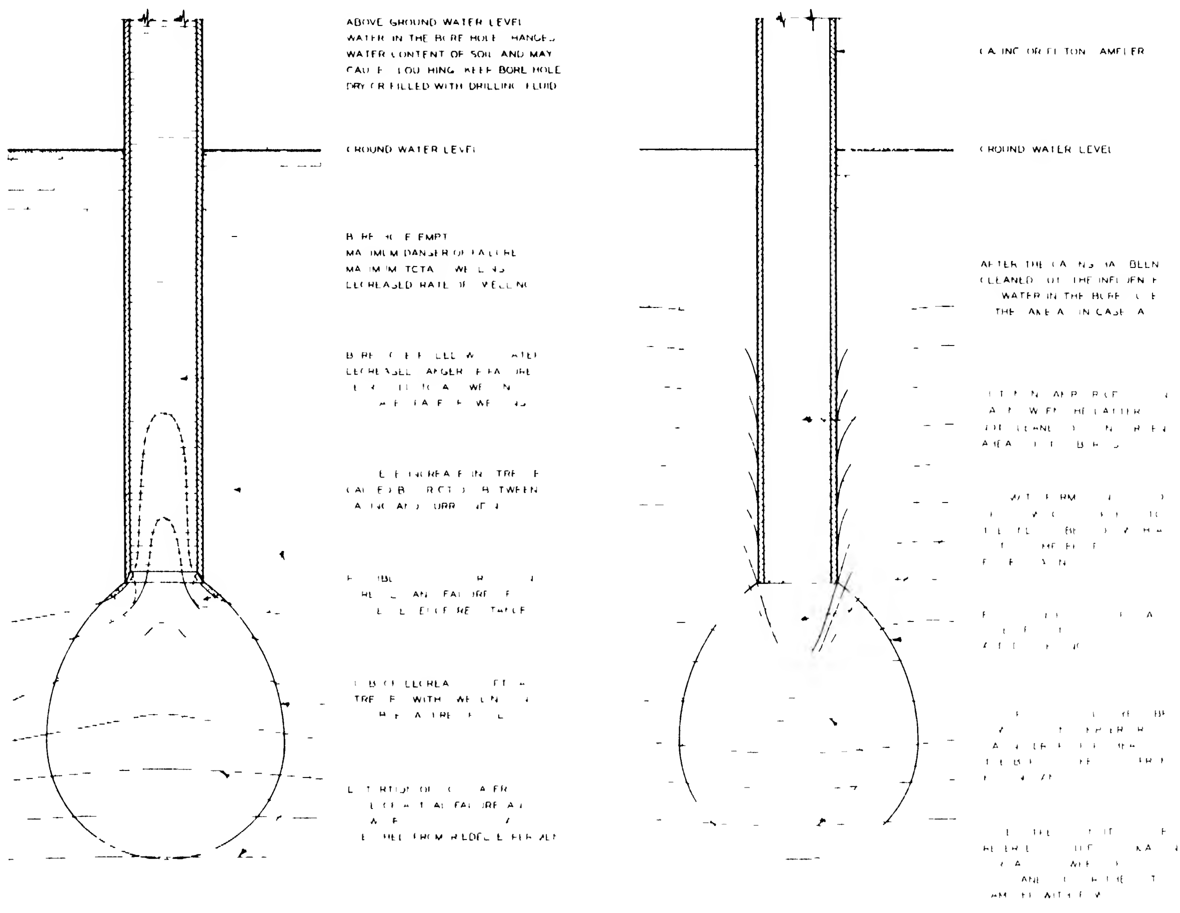
This chapter deals primarily with the general principles and the advantages and limitations of various methods and types of equipment used in obtaining and handling samples of subsurface materials, details of the sampling equipment and methods are described in Part II Reference is made to Section 1 2 for general definitions and classifications A detailed classification and a summary of the principal features and fields of application of the various types of samples are shown in Table 5

The first problem in the sampling of subsurface materials is, of course, to obtain a sample, that is, to get the material into the sampler and to keep it there during withdrawal of the sampler In undisturbed sampling the second, equally important, and more difficult problem is to obtain the sample with a minimum of disturbance of the material This disturbance may occur not only during the actual sampling but also before and after this operation The various causes of disturbance of the soil during boring and sampling operations and the subsequent handling of the sample are discussed in this chapter, and the outward manifestations of such disturbances are illustrated by photographs and diagrams obtained during the research Photographs showing soil stratifications, distortions of the strata, planes of failure, etc , were obtained after the samples had been sliced, partially dried, and carefully trimmed, the procedure is described in detail in Sections 16.10 to 16 12. A further discussion of the basic types of disturbance, their influence on the results of laboratory tests, and the requirements for undisturbed samples is presented in Chapter 6

4.2 Disturbance of the Soil below a Bore Hole

A review of the methods used for stabilizing or preventing caving of a bore hole was presented in Section 2 11, and it was pointed out that water in a bore hole above the ground-water level may cause sloughing or general failure of the soil or at least a change in the water content of the soil to be sampled The use of drilling fluid instead of water will eliminate danger of sloughing and decrease the change in water content, but the fluid may also penetrate into very porous materials and thereby contaminate the soil to be sampled. Therefore, bore holes above the ground-water level should, as far as possible, be kept dry when undisturbed samples are to be obtained.

When a bore hole is advanced by removing and not displacing soil, the vertical, normal stresses in the soil below the bottom of the hole will be reduced within a certain zone or bulb, Fig 71A The soil within this bulb of reduced stresses has a tendency to swell and may actually fail and flow into the bore hole when the stress reduction is large and the shearing resistance of the soil is small The stress reduction and the ultimate swelling can be reduced by filling the bore hole with water, but the initial rate of swelling will thereby be increased When there is only a small amount of water in the hole, both the rate and the total amount of swelling will attain their maximum values



A - BORING BY REMOVAL OF SOIL

B - BORING BY DISPLACEMENT OF SOIL

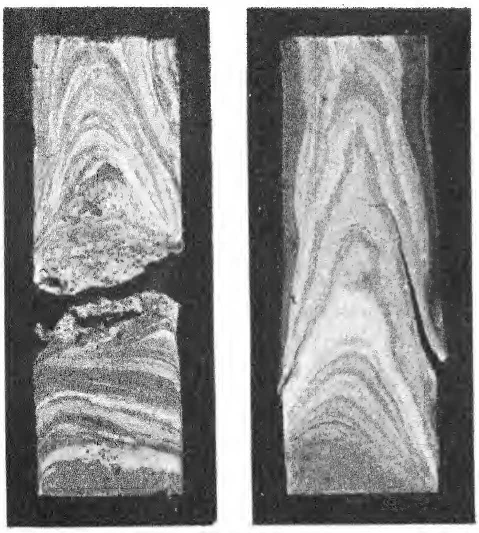
STRESS CHANGES AND DEFORMATIONS OF SOIL LAYERS BELOW BOTTOM OF BORE HOLE

FIG 71

When the stress reduction is so large or the shearing resistance of the soil so small that plastic flow of soil into the hole occurs, the soil below the bottom of the hole will be deflected upwards and seriously disturbed. **Riedel (961)** conducted experiments to determine the flow pattern and distortions when very viscous magma flows into volcanic pipes The results of these experiments apply also to the plastic flow of soil into a bore hole, and they indicate that visible distortions extend to a

depth approximately three times the diameter of the hole However, it is probable that the actual disturbance may reach much greater depths when a large amount of soil flows into the hole Soil layers in samples taken from this disturbed zone will have a convex curvature, Fig 72, but it is difficult to determine whether samples with this type of strata distortion have been disturbed by failure of the soil below the bottom of the bore hole, since similar distortions may be caused by friction between sample and sampler and by entrance of excess soil, displaced by the walls of the sampler, see Fig 75, 89A, and 90

The greatest stress reduction occurs when a sampler is withdrawn and a partial or full vacuum created below the sampler The danger of failure and disturbance of the soil is further increased by the tensile or torsional stresses which are produced in separating the sample from the subsoil However, the failure may be a progressive phenomenon, and it is often observed that the actual caving of the hole is delayed and occurs during interruptions of boring and sampling operations In soils requiring casing of the bore hole and stabilization with water or drilling fluid, it is therefore important that the casing be advanced as soon as possible after withdrawal of the sampler, and that the hole be kept filled with water or drilling fluid during interruptions of the operations Even when failure does not occur, the soil within the bulb of reduced stresses will be subject to progressive swelling, and the sample should always be taken as soon as possible after the advance and cleaning of the bore hole



MEDIUM SOFT SILTY CLAY
DEPTH 92'
2" SHELBY TUBING - PUSHING

A

MEDIUM SOFT SILTY SANDY CLAY
DEPTH 44'
2" SHELBY TUBING - PUSHING

B

DISTORTIONS PROBABLY CAUSED BY CAVING

FIG 72

MEDIUM SOFT SILTY CLAY
DEPTH 39'
2" THIN WALL SAMPLER

SOIL CONE FORMED BY PISTON SAMPLER

FIG [illegible]

ORGANIC SAND CLAY SILT
DEPTH 10'
6" ST. PAUL SAMPLER - HYDRAULIC DRIVE

SOIL CONE FORMED BY OVER-DRIVING IN PREVIOUS SAMPLING

FIG 7[illegible]

When the bore hole is advanced by displacement of soil, a bulb with increased stresses and downward deflection of the soil layers will be created below the bottom

DISTORTIONS CAUSED BY CAVING OR IMPROPER CLEANING

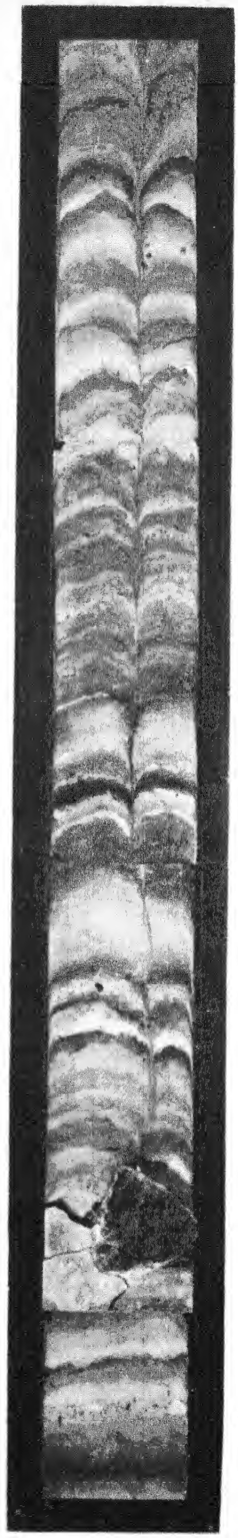
FIG. 75

MIXING AND DISTORTION CAUSED BY IMPROPER CLEANING

FIG. 76

DISTORTIONS CAUSED BY SHAVINGS OF STICKY SOIL

FIG. 77



DISTURBANCE CAUSED BY STONE AT CUTTING EDGE

FIG. 78

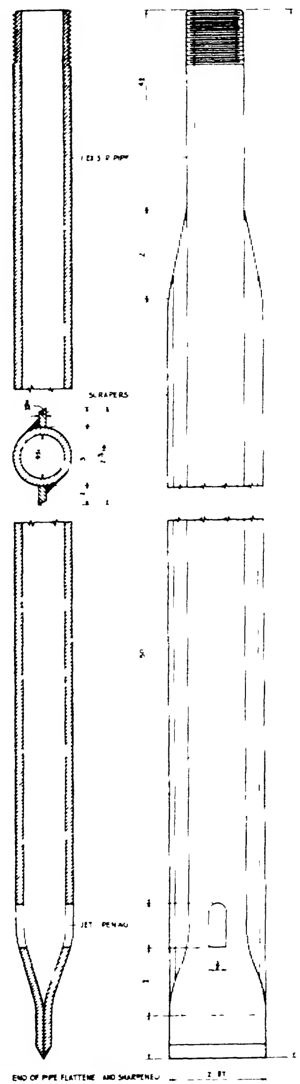
ALL 4 SAMPLES = SOFT TO MEDIUM SOFT SILTY CLAY (SOFT BOSTON BLUE CLAY) - DEPTH 26' TO 53' - 2" OPEN SHELBY TUBING SAMPLER - PUSHING

of the hole or the bottom of the closed sampler used in advancing the hole, Fig 71B The upper part of the sample will then have concave distortions of the soil layers or shear failures for a distance of one to two times the diameter, Fig 73, but the actual disturbance may extend to a depth of three times the outside diameter of the sampler or the diameter of the bore hole A similar condition and distortions may be created by overdriving of the sampler in the previous sampling operation, Fig 74, or by advancing the casing ahead of the bore hole The casing will then act as a sampler, but it has a cutting edge on the outside of the shoe, and the inside friction increases rapidly so that an immovable plug of soil soon will be formed in the casing and a bulb of increased stresses below the casing Subsequent cleaning of the casing will to some extent reverse the stress conditions and may thereby counteract the initial compaction or consolidation of the soil within the bulb of increased stresses, but the stress reversal may also cause further disturbance of the soil structure There is also a zone of increased distortion and disturbance close to the cutting edge of the casing, hence the hole should preferably be advanced and cleaned for a short distance below the casing before a sample is taken

Fven with the above mentioned precautions it is difficult to avoid a partial disturbance of the soil in the vicinity of the bottom of the bore hole and thereby of the upper part of the sample This is especially the case when continuous samples are taken, since the disturbance then is increased by the torsion or tensile stresses produced when the sample above was separated from the subsoil When it is desired to reduce the length of the disturbed part of the samples, the bore hole should be advanced and cleaned to a depth of two to three times its diameter below the bottom of the previous sample

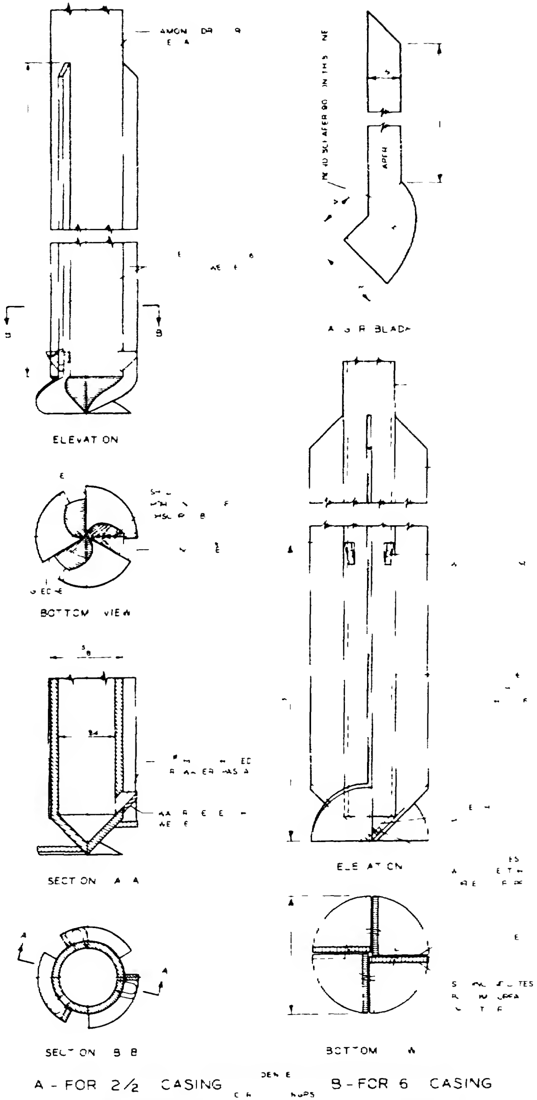
4.3 Cleaning of the Bore Hole

Careful cleaning of the bore hole is the first requirement for obtaining representative or undisturbed samples with an open drive sampler. Careless and incomplete cleaning is one of the most frequent causes of serious disturbance of the upper part of the sample, in extreme cases the entire sample may consist of seriously distorted, mixed and segregated soil The distortions shown in Fig 75 may be caused by caving of the bottom of the hole, they may also be caused by advancing the casing into the undisturbed soil and not cleaning the hole to the edge of the casing. Fig 76 shows an example of disturbance of the soil by boring or cleaning tools and failure to clean the hole completely of accumulated sludge and settled material The upper part of the sample shown in Fig 77 likewise consists of mixed material, whereas the distortions in the lower part may have been caused by disturbed and sticky material adhering to the walls of the sampling tube and thereby forming a restricted opening through which the underlying soft soil is forced. Pebbles and stones, not removed in the cleaning or encountered in the undisturbed soil, may damage the cutting edge thus causing partial disturbance of the entire sample The stones may also be caught on, or may ride on, the cutting edge and will then cut the sample lengthwise



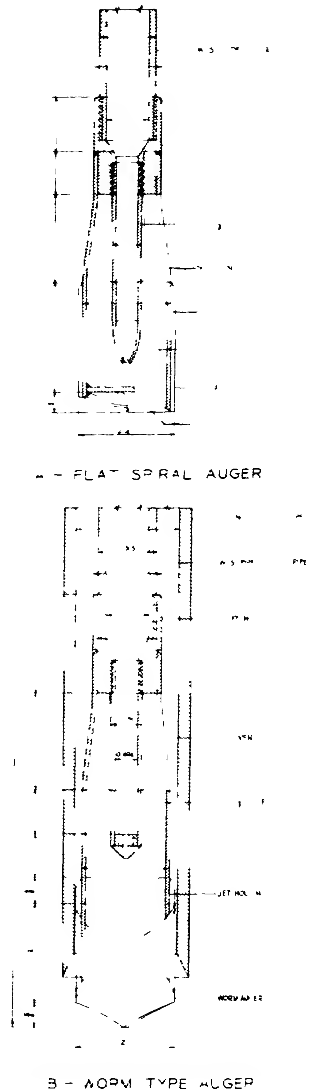
WASH PIPE WITH SCRAPERS

FIG 79



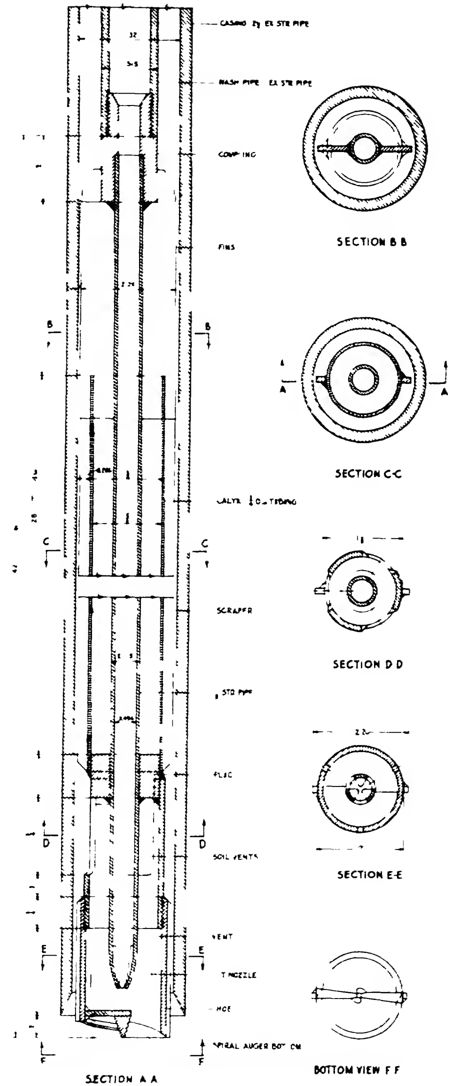
PROVIDENCE CLEAN-CUT AUGERS

FIG 80



SHIELDED JET AUGERS

FIG 81



CLEAN-CUT AUGER WITH CALYX

FIG 82

until they finally are pushed aside or forced into the sampler, Fig 78 Similar disturbances which did not terminate with a stone were observed in several samples examined during the research, and it was not until samples were obtained in which the stone was forced into the sampler that the cause of this type of disturbance could be verified The distortions generally start near the top of the sample and are then caused by stones which should have been removed during the cleaning of the bore hole.

The methods and equipment for advancing a bore hole can be and are often used to clean it, but special equipment is generally required when open drive samplers are used and when undisturbed samples are to be obtained Cleaning by means of washing is used extensively when the bore hole is filled with water or drilling fluid The jet holes in wash boring bits are generally directed downward to increase the efficiency of the jet, but a strong, downward directed jet may erode soft or cohesionless soils to an unknown depth, and the eroded hole may eave in or be filled with coarse sediment when the washing is stopped The jet holes in cleaning tools should preferably be directed upward or shielded to prevent uncontrolled erosion, but a horizontal jet may be used within a casing Examples of such tools are shown in Fig 79-82

When open drive samplers or core barrels are used, the cleaning and washing should be continued until all disturbed material at the bottom and all material which may settle out during the interval between the cleaning and the sampling have been removed Complete cleaning by washing alone may require considerable time when the bore hole is deep or the diameter is large, and it is often difficult to judge whether all coarse material or lumps of strongly cohesive and sticky soil have been removed from a deep bore hole In such cases it is advantageous to provide the clean-out tool with a sludge barrel or calyx in which the coarse or unbroken material will settle An example of a clean-out auger with shielded jet and calyx, designed and built in cooperation with the Boston office of the Raymond Concrete Pile Company, is shown in Fig 82 Similar clean-out augers for 4- and 6-in casing were also built Their use not only decreased materially the time required for cleaning, but it also produced a cleaner hole

It is not always possible to remove pebbles and stones by the clean-out tools described above Bailers, sandpumps, or barrel augers are often used in such cases and for cleaning in general, but bailers and sandpumps are not well suited for the final cleaning when the undisturbed soil consists of very soft clay, silt, or fine sand, since the chopping action and the suction created by the upstroke may disturb the soil to be sampled It may be necessary to take a short disturbed sample in order to remove large pebbles and stones A clean-out barrel with a flared-out cutting edge and often provided with flap valves is occasionally used for this purpose as well as for cleaning dry bore holes

Less thorough cleaning or no cleaning at all is required when piston samplers are used in uncased parts of a bore hole, but care should be taken to push such a sampler through the disturbed material before the piston is released and the actual

sampling is started. Cased bore holes should be cleaned to the edge of the casing even when piston samplers are used, since the disturbed material in the casing cannot be displaced laterally but will be pushed ahead of the sampler and disturb the soil to be sampled.

4.4 Summary -- Advance and Cleaning of the Bore Hole

The following summary does not deal with the merits and limitations of the various boring methods but only with general precautions and procedures which will reduce the disturbance of the soil to be sampled and which should be observed when undisturbed samples are desired.

(1) **Stabilization.-** Bore holes in relatively unstable soils should be stabilized with casing or drilling fluid, even though a gradual caving or limited zone of failure does not seriously interfere with boring operations. Casing is required for accurate ground-water observations.

(2) **Boring above ground-water level.-** When undisturbed samples are desired, the bore hole should preferably be kept dry; it may be filled with drilling fluid but not with water.

(3) **Boring below ground-water level.-** The bore hole should preferably be filled with water or drilling fluid, at least when soft or cohesionless soils are encountered and during protracted interruptions of the work. A bore hole in stiff soil may be kept dry, but it should then be completely dry, since a small amount of water in the hole is the most unfavorable condition in regard to both swelling and failure of the soil.

(4) **Advance of casing.-** When approaching sampling depth, the bore hole should be advanced a little ahead of or concurrently with the casing, and the latter should not be driven ahead of the boring unless required to prevent caving. Vibration should be avoided as far as possible, especially when undisturbed samples of cohesionless soils are to be taken, in which case the casing should be advanced by jacking, rotation, or jetting and not driven by a hammer.

(5) **Cleaning for open samplers.-** The bore hole should be completely cleaned of disturbed soil and segregated coarse material and also of clay adhering to the walls of the casing. The cleaning should be extended at least to the edge of the casing and should preferably advance the hole a short distance further in order to by-pass the disturbance caused by the cutting edge of the casing. The cleaning should never be done with a strong downward directed jet. A pipe with horizontal jet openings may be used within the casing, but a wash pipe with scrapers and shielded jet, clean-out augers with calyx, or barrel augers are preferable and should be used when the hole is advanced below the casing. Sandpumps and bailers should be used with discretion in soft soils and in fine-grained cohesionless soils.

(6) **Cleaning for piston samplers.-** The requirements for careful cleaning are

less exacting than those for open samplers, provided the closed piston sampler is pushed through the disturbed material before the actual sampling is started However, a cased bore hole should be cleaned to the edge of the casing, since soil in the casing cannot be displaced laterally No cleaning is required when the bore hole is uncased and the closed piston sampler is forced into undisturbed soil

(7) **Time factor.-** Swelling, plastic deformations, and actual failure of the soil may require considerable time for full development The soil to be sampled should not be exposed to these sources of disturbance for longer periods than necessary, and the sample should be taken as soon as possible after cleaning of the hole The casing should be forced to the new bottom of the hole immediately after withdrawal of the sampler, but the hole should not be advanced further and cleaned unless a new sample can be taken before protracted interruptions of the work

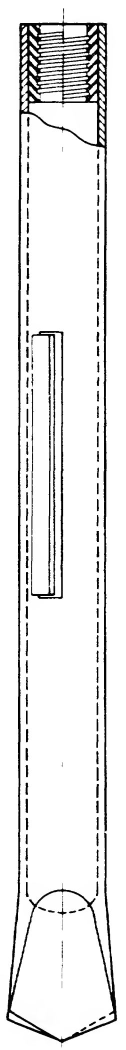
(8) **Spacing of samples.-** Separation of the sample from the subsoil and withdrawal of the sampler may cause disturbance of the soil near the bottom of the hole. When fully continuous samples are not required and undisturbed samples are desired, it is advisable to leave an interval between samples at least equal to two to three times the diameter of the hole When continuous samples are required and taken, the upper part of each sample should not be used for tests requiring undisturbed soil

4.5 Exploration Samplers

This group includes bailers, sandpumps, augers, slit tube, and cup samplers, which are used both for advancing and cleaning the bore hole and for obtaining fairly representative but not undisturbed samples Bailers, sandpumps, and augers constitute boring and cleaning equipment rather than samplers and have already been described, see Sections 2.14 and 2 16.

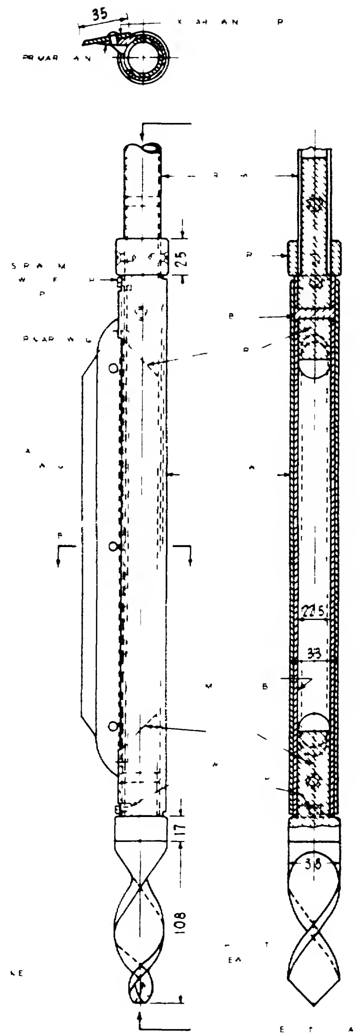
A slit tube sampler consists in its simplest form of a tube with a longitudinal slit and with the lower end of the tube closed to form a bit or point, Fig 83. The tube is driven to the desired sampling depth and then rotated so that soil enters the tube through the slit There is danger that some soil from overlying strata may pass through the slit during both the driving and the withdrawal of the tube This disadvantage is eliminated in the Swedish slit tube sampler, Fig 84, in which the slit is covered with a hinged flap, which opens and admits soil to the tube when the sampler is rotated counterclockwise and closes the slit by clockwise rotation The sample consists of a mixture of soil from a depth interval equal to the length of the slit A decrease of the depth interval of mixing and more representative samples are obtained with the Ellms slit tube sampler, Fig 85, which has several separated but short slits with individual flaps and sample containers

A sampler with a circumferential slit and called a cup sampler, Fig. 86, has been developed by the late Mr. A M Blamphin for the New Orleans District, Corps of Engineers (115). The drive point and sample cup are supported by a rod and spring in such a manner that, at the start of the withdrawal, they remain stationary until the



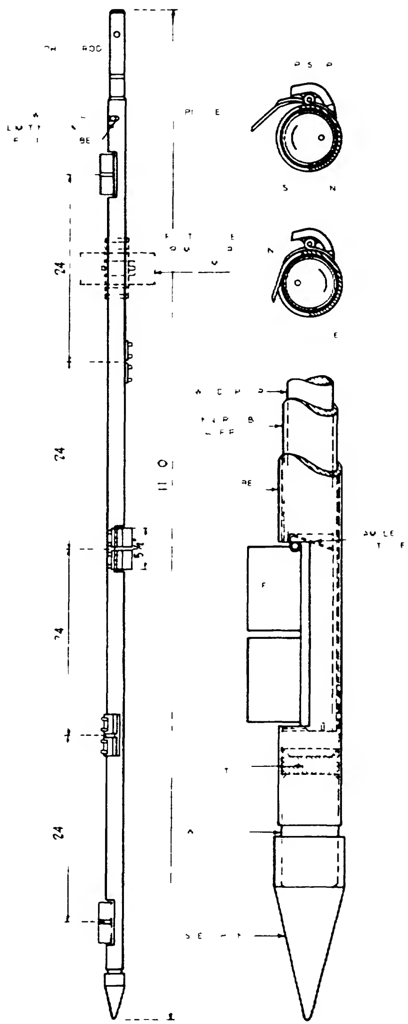
SIMPLE SLIT TUBE SAMPLER

FIG 83



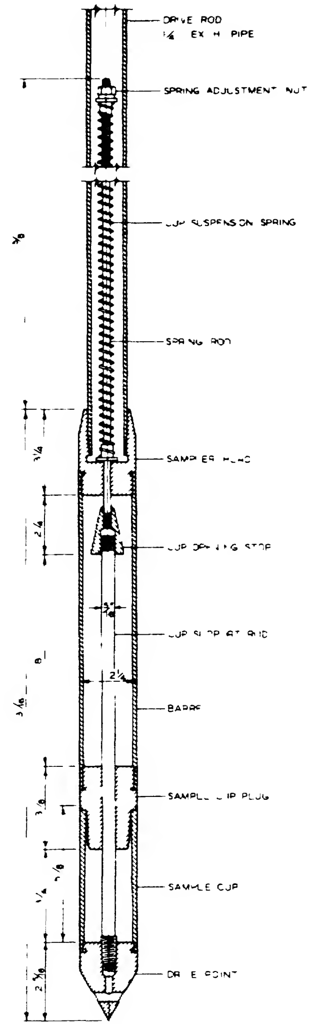
SWEDISH SLIT TUBE SAMPLER

FIG 84



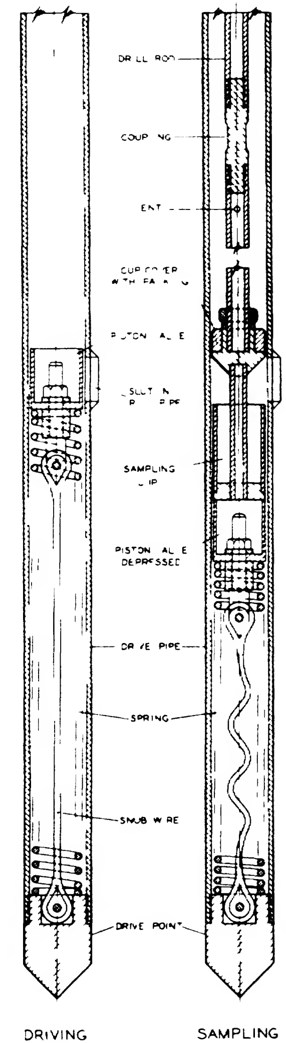
SLIT TUBE SAMPLER BY ELLMS

FIG 85



NEW ORLEANS CUP SAMPLER

FIG 86



SWEDISH CUP SAMPLER

FIG 87

plug and upper barrel have been moved upwards for a short distance The slit is thereby opened, and soil is scraped off the walls of the hole and collected in the cup

The hole produced by the above mentioned slit tube and cup samplers may cave in when the sampler is withdrawn, and considerable energy may be required to force the emptied sampler through the caved part of the hole in order to obtain samples of deeper strata This disadvantage is eliminated in the Swedish cup sampler, Fig 87, which consists of a drive pipe with a drive point and a short slit The latter is temporarily closed by a spring-actuated piston valve When a sample is desired, a cup attached to a rod is lowered into the drive pipe, and the piston valve is depressed until the top of the cup is slightly below the slit in the drive pipe The latter is then rotated until sufficient soil has passed through the slit to fill the cup, whereupon the cup with the sample -- but not the drive pipe -- is withdrawn, and the slit is again closed by the piston valve

The samples obtained with slit tube and cup samplers are seriously disturbed, and these samplers are therefore suitable only for reconnaissance exploration They are primarily used for relatively shallow depths of exploration and in deposits of loose, fine sand, silt, and very soft soils, samples of which are often difficult to obtain by means of drive samplers

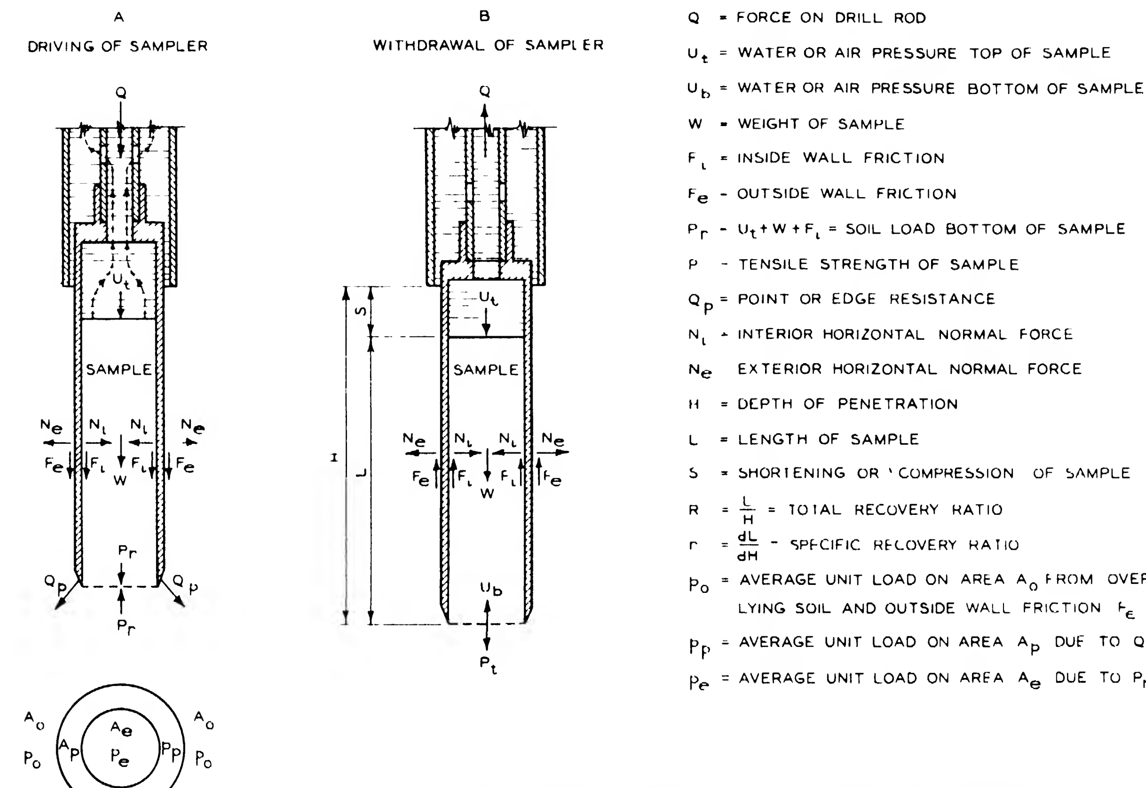
4.6 Drive Sampling -- Forces and Deformations

In principle a drive sampler is a tube which is forced into the soil without any rotation or chopping action and without removing the soil displaced by the walls of the sampler This soil is simply pushed aside with consequent severe stress changes and plastic deformations in the surrounding soil A simplified and rough analysis of the forces and deformations during the drive sampling operation is presented below, but it has not yet been possible to determine definitely the extent and influence of some of the stress changes or the actual causes of some forms of distortion of the soil layers

Forces during the driving.- The forces acting while a drive sampler is being forced into the soil are shown in Fig 88A The pressure on top of the sample, U_t, and the inside wall friction, F_i, tend to compress and distort the soil layers and to increase the pressure, p_e, on the circular area, A_e, directly below the sampler. The pressure, p_p, on the surrounding annular area, A_p, is very high on account of the edge resistance, Q_p, and a part of the soil below this area must be displaced as the sampler is forced into the soil Outside the annular area the pressure, p_o, is governed by the weight of overlying soil and the outside wall friction, F_e Although the forces F_e and F_i primarily depend on the horizontal, normal forces, N_e and N_i, and the coefficient of friction between the wall of and the soil in the sampler, they may in some cases be increased considerably by adhesion between the soil and the wall

Entrance of excess soil.- As the sampler advances, a part of the soil under

the annular area, A_p, is displaced by the walls of the sampler and pushed aside During the first part of the drive, while the inside wall friction and the pressure, p_e, still are small, some of the displaced soil may be forced into the sampler It will



FORCES ACTING DURING THE DRIVE SAMPLING OPERATION

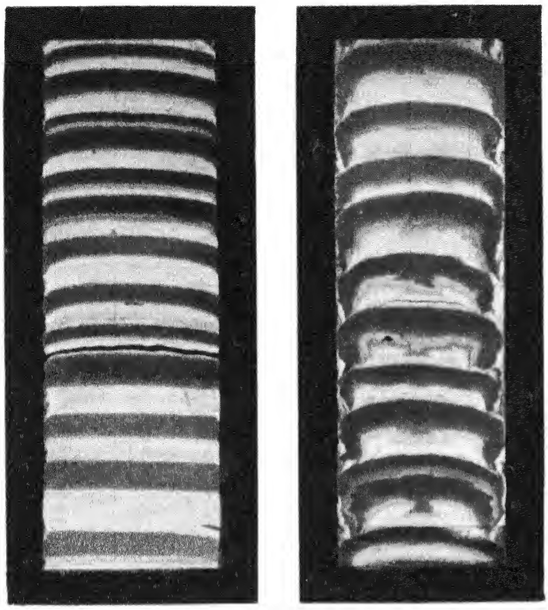
FIG 88

thereby increase the thickness and cause convex distortions of the soil layers in the upper part of the sample When the entrance of excess soil is relatively small, the distortions have a fairly uniform curvature, Fig 89A, but when the entrance of excess soil is so large that the thickness of the soil layers is increased by more than 30 per-cent, the distortions assume a characteristic shape resembling that of a flattened bulb, Fig 89B

The possibility of entrance of excess soil increases with increasing amounts of displaced soil or increasing wall thickness of the sampler, and also with increasing values of p_o in relation to p_e and thereby with increasing depth of the bore hole Entrance of excess soil can be reduced or prevented by using a sampler with very thin walls or a cutting edge with a very flat taper, by increasing the velocity with which the sampler is forced into the soil, and by the use of a stationary piston, see Section 4 12 In all cases the possibility of entrance of excess soil decreases with increasing length of the sample and a corresponding increase in p_e, until finally p_e becomes so large that all the displaced soil is forced outwards into the surrounding soil

Influence of the inside wall friction.- The inside wall friction and a positive pressure, U_t, on top of the sample increase the pressure, p_e, below the sampler and

thereby tend to compact the soil before it enters the sampler Such a compaction may later be offset by swelling if the diameter of the cutting edge is smaller than the inside diameter of the sampler, Section 4 8 The inside friction also tends to pro-

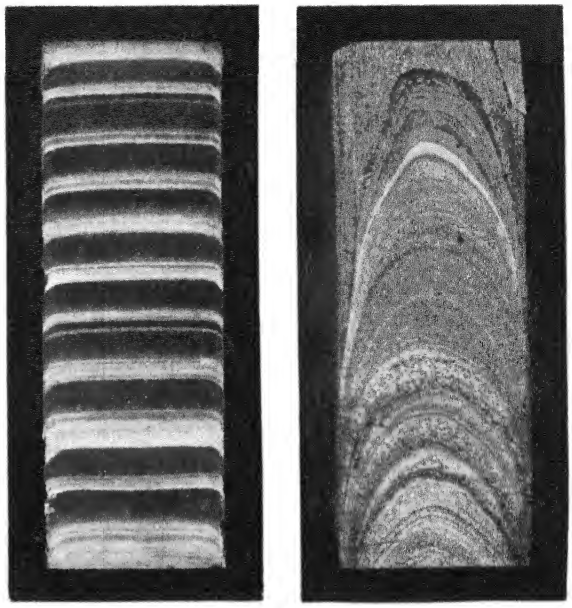


A B

SPECIFIC RECOVERY 100% [illegible] SPECIFIC RECOVERY 140% 154%
VARVED CLAY DEPTH [illegible] PIGGOT SAMPLER [illegible] JACKING

DISTORTIONS BY ENTRANCE OF EXCESS SOIL

FIG 89



A B

VARVED CLAY - DEPTH 5 [illegible] SAMPLER [illegible]
SANDY AND SILTY CLAY DEPTH 18 - SHELBY TUBING HAMMERING

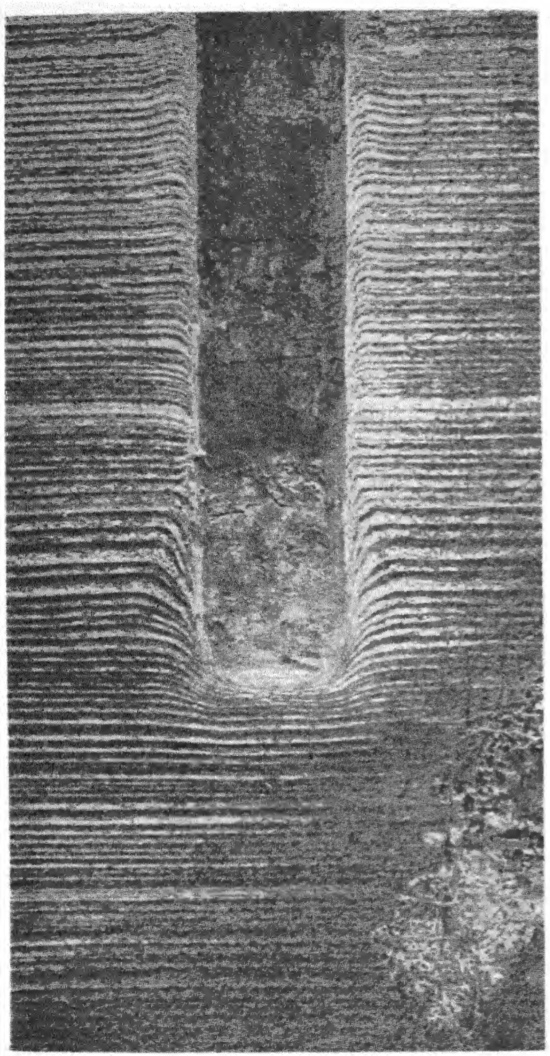
DRAG AND DISTORTION BY INSIDE FRICTION

FIG 90

duce a convex curvature of the soil layers The distortion is generally small in the central part and increases sharply and may be confined entirely to a zone of "drag" close to the surface of the sample, Fig 90A In a properly designed and operated sampler the zone of drag will be very small or practically eliminated However, very large convex distortions, nearly parabolic in shape, are in some cases produced by the inside wall friction, Fig 90B These distortions resemble those produced by plastic flow of soil into the bore hole, Fig 71 and 72, and it is as yet difficult, from an examination of the sample alone, to determine the actual cause of such distortions

The inside wall friction also governs the pressure on and the disturbance of the soil below the sampler, and it is the most important single source of disturbance of the soil during the sampling operation It can be reduced by polishing and oiling or lacquering and by a slight reduction in diameter of the cutting edge to provide inside clearance As suggested by **Kjellman and Kallstenius (147)**, detrimental effects of the inside friction may be eliminated by use of sliding steel foils, see Section 10 5

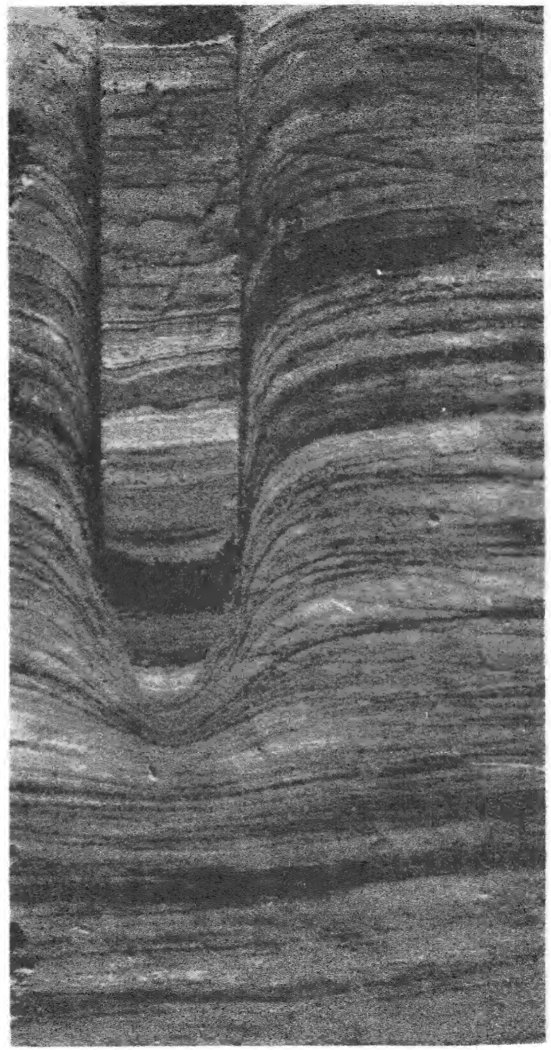
Deflection and failure of soil below the sampler.- The total inside wall friction and thereby also the pressure, p_e, on the soil below the sampler increases with the



$4\frac{3}{4}$" M.I.T. SAMPLER – HAMMERING

START OF DOWNWARD DEFLECTION OF SOIL LAYERS

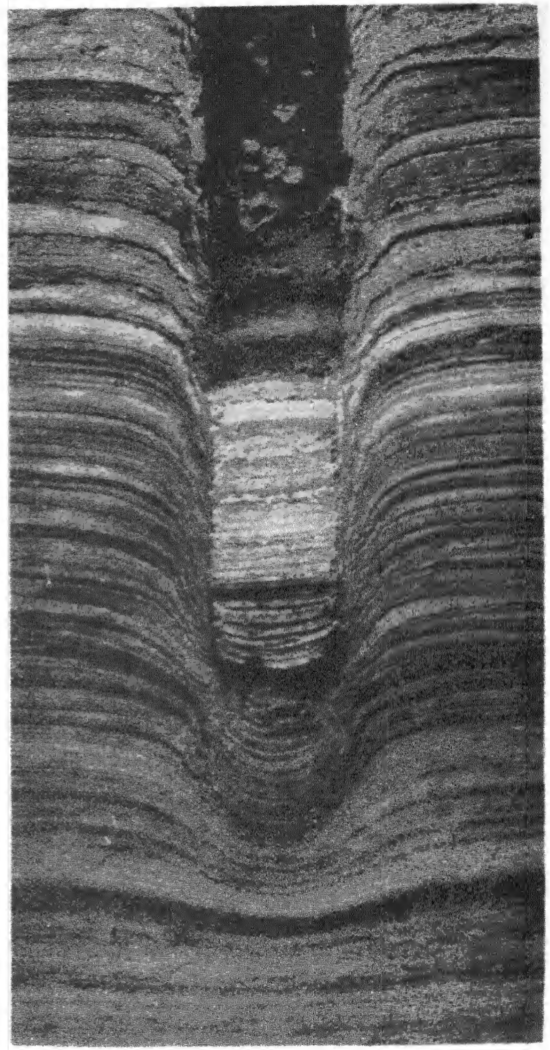
FIG. 91



2" SHELBY TUBING – SINGLE BLOW

FORMATION OF SOIL CONE BELOW SAMPLER

FIG. 92



2" SHELBY TUBING – SLOW JACKING

FORMATION OF SOIL BULB BELOW SAMPLER

FIG. 93

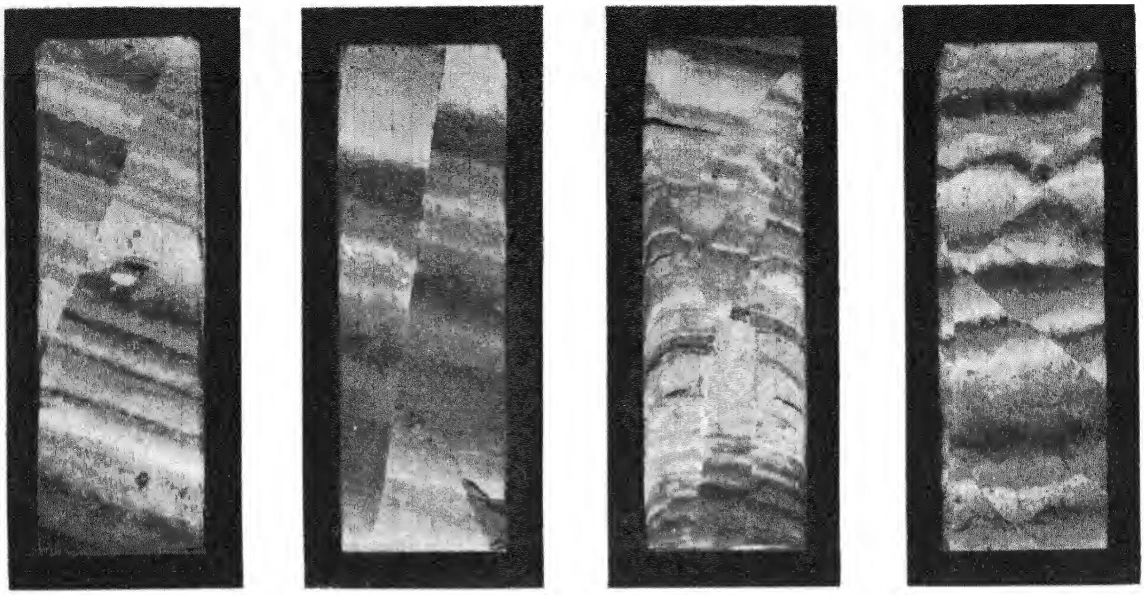
penetration of the sampler and the length of the sample The first effect of an increase in the pressure, p_e, is to decrease and later prevent entrance of excess soil, but with increasing penetration p_e will finally exceed the bearing capacity of the soil From then on the soil layers below the sampler will be deflected downward, stretched, and reduced in thickness before they enter the sampler, Fig 91 Shear failures may occur before or concurrently with the downward deflection, Fig 94 As will be seen in Fig 91, the soil layers directly below the sampler are still fairly straight in spite of a material deflection and decrease in thickness At a still greater penetration of the sampler and deflection of the soil layers, the latter will assume a distinct concave curvature, Fig 95 This curvature, especially near the surface of the sample, may be reversed after the soil enters the sampler and is exposed to direct action by the inside wall friction, Fig 108

In soils consisting of alternating thin strata of varying shearing resistance, soft strata will be subject to a greater decrease in thickness than stiff strata and may to a large extent be squeezed out, whereas stiff strata are broken up and mixed with the remnants of soft strata Such a partial elimination of soft strata from the lower part of long samples was first observed and explained by **Pratje** (729).

Ultimately, the inside friction becomes so large that it prevents further entrance of soil into the sampler A permanent cone or bulb of soil is then formed below and forced into the soil with the sampler, Fig 92 and 93, which now acts as a solid rod or pile Such a cone will also be formed when the driving of a short sampler is continued after it is completely filled with soil When the bore hole is not advanced before the next sample is taken, the upper part of this sample will be seriously disturbed and contain the cone, Fig 74

Influence of pressure or vacuum over the sample.- Very large hydrostatic pressures may be created over the sample when the vent area is small and the velocity of penetration is large, as when the sampler is forced into the soil by means of a drop hammer A large positive pressure over the sample will increase both vertical and horizontal normal stresses in the sample and thereby the inside wall friction and the pressure, p_e, on the soil below the sampler, and it will consequently decrease the depth of penetration at which a downward deflection of the soil layers starts and at which a permanent soil cone is formed below the sampler

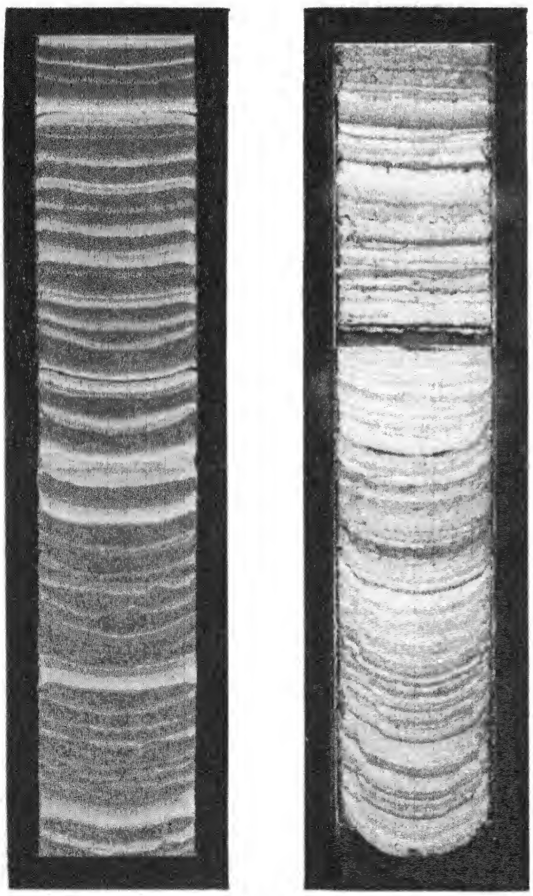
A decrease in pressure over the sample or the formation of a partial vacuum by means of a suction hose and a vacuum pump or a stationary piston, see Sections 4 11 and 4 12, will have the opposite effect However, too great a reduction of this pressure and a consequent strong upward flow of water through the sample may cause piping and serious disturbance of samples of cohesionless soils, Fig 96A Even when piping and partial liquefaction do not occur, fine-grained constituents of the soil may be removed by the flow of water In several instances it has also been observed that an excessive decrease of pressure over samples of very soft and sticky soils caused the center of the sample to be pushed upwards whereas soil near the cylindrical surface adhered to the walls of the sampling tube, Fig. 96B



A – SINGLE INCLINED PLANE B – SINGLE VERTICAL PLANE C – FORMATION OF WEDGE D – MULTIPLE SHEAR PLANES

MEDIUM SOFT SILTY CLAY – DEPTH 25' TO 47' – 2" SHELBY TUBING – PUSHING – PENETRATION 42" TO 48" – RECOVERY 90% TO 95%

FIG. 94 – EXAMPLES OF SHEAR FAILURES CAUSED BY SAMPLING

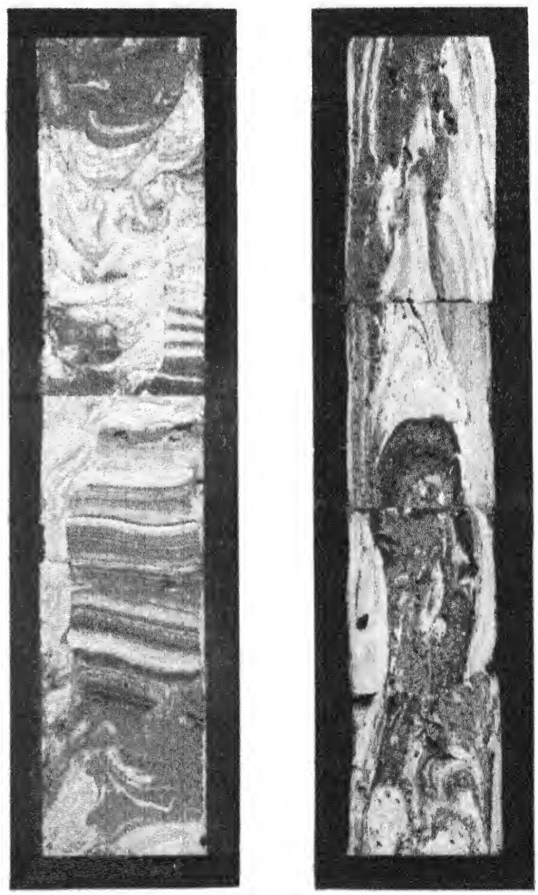


A B

VARVED CLAY – H = 54", L = 37" CLAYEY SANDY SILT – H = 47", L = 23"

2" SHELBY TUBING – NO INSIDE CLEARANCE – SINGLE BLOW

FIG. 95 – DISTORTIONS CAUSED BY OVERDRIVING



A B

SILTY SAND – DEPTH 55' ORGANIC SOFT SILTY CLAY – DEPTH 20'

2" THIN-WALL PISTON SAMPLER – PUSHING – H = 42", L = 32" TO 33"

FIG. 96 – DISTURBANCE CAUSED BY VACUUM OVER SAMPLE

Influence of the outside wall friction.- The outside wall friction, F_e in Fig 88, increases the penetration resistance of the sampler and also the pressure, p_e, on the soil below but outside the sampler An increase of p_o will promote entrance of excess soil during the first part of the drive, but it will also increase the bearing capacity or critical load, p_e, on the soil directly below the sampler, thereby delaying the actual failure and distortion of this soil and increasing the length of sample which can be obtained in a single operation Systematic experiments to determine the influence of the outside wall friction to the exclusion of all other variables were planned but had to be abandoned, see also the discussion of the outside clearance in Section 4 8.

Forces during the withdrawal.- The direction of the wall friction is reversed during the withdrawal, Fig 88B To retain the sample the sum, $F_i + U_b$, of the inside wall friction and the hydrostatic pressure on the bottom of the sample must be greater than the sum, $U_t + W + P_r$, of the pressure on the top, the weight, and the tensile strength of the sampler, that is, the inside wall friction and the hydrostatic pressure on the bottom of the sample should be large, whereas the pressure on the top and the tensile strength should be small and preferably eliminated When the above mentioned requirement cannot be fulfilled, the sample must be supported by a core retainer

The requirement that the inside wall friction should be large during the withdrawal is opposed to the requirement that it should be small during the drive, hence, the permissible reduction of the inside wall friction is limited unless a core retainer is used. However, the inside wall friction can be increased to some extent after the drive by delaying withdrawal operations This delay allows expansion and swelling to be completed and a thin layer of disturbed soil on the surface of the sample to regain strength and increase the adhesion between the soil and the walls of the sampling tube

The pressure over the sample can be reduced by means of a check valve or a piston or by a suction hose and a vacuum pump The tensile strength of the sample can be partially eliminated by rotating the sampler or cutting the sample by means of a snare wire concealed in the sampler shoe The withdrawal tends to produce a partial vacuum below the sample until the sampler is out of the soil at the bottom of the bore hole This reduction of the upward pressure, U_b, is a common cause of loss of samples When necessary, the pressure, U_b, can be maintained and even increased by providing channels for admission or injection of water or compressed air below the sample.

Samples of loose, cohesionless soils and of extremely soft soils are often lost even though the requirements for statical equilibrium are satisfied The sample is primarily supported along its cylindrical surface, and when the diameter becomes too large, internal failure of the soil occurs and causes progressive loss of the sample. Such a loss can be prevented by use of core retainers; by overdriving the sampler, and compacting the lower part of the sample; or by freezing the bottom of the sample.

An examination of the various forces acting on the sample during withdrawal shows that difficulties in retaining the sample generally decrease with increasing length and increase with increasing diameter of the sample

Disturbance during the withdrawal.- When the sample is separated from the subsoil by a direct pull or rotation, the necessary tensile or torsional forces must be transmitted from the walls of the sampling tube to the soil over a certain length of the lower part of the sample These forces will generally cause a partial disturbance of the lower part of the sample, and this disturbance may be increased by swelling on account of contact with free water in the bore hole and/or internal migration of water from the undisturbed to the partially disturbed sections, or vice versa, see Chapter 6 and Fig 140A

The above mentioned tensile or torsional forces will, of course, also disturb the soil below the sampler, and the extent of this disturbance will be increased and actual caving may occur if a partial vacuum is created below the sampler during the first part of the withdrawal

4.7 Recovery Ratios

The principal dimensions of a drive sampler and the measurements which should be made during the sampling operation are defined in Fig 97A In order to express the results of the sampling operation and to formulate design requirements, it has been found convenient to use certain ratios between these measurements and dimensions

The over-all condition of a soil sample is represented by the

$$\text{Total Recovery Ratio} = \frac{L}{H}$$

where H is the penetration of the sampler below the bottom of the bore hole or during the actual sampling, and L is the length of the sample before the withdrawal When the sample does not move downwards in the sampling tube during the withdrawal, the total recovery ratio is equal to the

$$\text{Gross Recovery Ratio} = \frac{L_g}{H}$$

where the gross length of the sample, L_g, is equal to the distance from the top of the sample to the cutting edge irrespective of whether the lower part of the sample is lost The gross and not the net length, L_n, of the sample should be used in computing the recovery ratio for soil samples, since the condition of the recovered sample is not influenced by a loss of the lower part of the sample. Nevertheless, the net length should also be determined for control purposes, see Section 4 21, and the

$$\text{Net Recovery Ratio} = \frac{L_n}{H}$$

is generally used as a measure of the success of core boring operations in rock,

since it indicates the length of the recovered core in relation to the depth or advance of the bore hole A rock sample is not deformed like a soil sample, and the condition of the recovered sections is therefore not represented by the total recovery ratio All recovery ratios are often expressed as a percentage instead of a fraction

The difference between the penetration and total length, $S = H - L$, is often called the compression of the sample, but this term is misleading, and the term "shortening" would better express the actual condition Some compaction of cohesionless or partially saturated soils may occur during sampling, but whenever S is large, the reduction in length of the sample is primarily caused by a downward deflection and stretching of the soil layers, as described in the foregoing section. It should also be noted that the original thickness of the strata represented by the sample is not H but $(H - F)$, where F is the downward deflection of the strata at the cutting edge, and that the true total recovery ratio therefore is $L / (H - F)$

In most samplers the diameter of the cutting edge, D_e, is made slightly smaller than the inside diameter of the tubing, D_s, in order to permit a small lateral expansion of the sample and reduce the inside friction When the inside clearance produced by the decrease of D_e exceeds that required to compensate for the elastic expansion of the soil after it enters the sampler, it may cause a shortening of the sample The maximum shortening occurs when there is no elastic expansion or volume change, and when the sample slumps or deforms laterally until it is in contact with the walls of the sampling tube Assuming further that there is no entrance of excess soil and no downward deflection and stretching of the soil layers, the length of the sample is determined by $L = H \times (D_e / D_s)^2$ By introducing the inside clearance ratio $C_1 = (D_s - D_e) / D_e$ -- see Fig 97A and Section 4 8 -- the above equation may be written $L = H / (1 + C_1)^2$ or with fair approximation for small values of C_1,

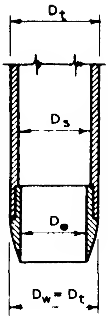
$$L = H (1 - 2C_1)$$

Therefore, the sample may be undisturbed even when the total recovery ratio is $R = L / H = (1 - 2C_1)$, provided the lateral expansion of the sample is not so large that it causes disturbance of the soil structure

The total or gross recovery ratio does not furnish any information on the change in thickness of the individual sections of the sample, nor is it a reliable indicator of the condition of the sample unless the entrance of excess soil is prevented or reduced to a negligible amount However, it is possible to determine corresponding values of H and L while the sampler is being forced into the soil and thereby to determine corresponding increments, ΔH and ΔL, and the

$$\text{Specific Recovery Ratio} = \frac{\Delta L}{\Delta H}$$

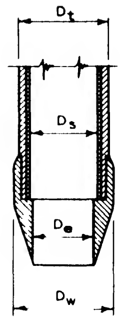
which indicates the condition of or the approximate change in thickness of the individual increments of the sample When there is a downward deflection of the soil before it enters the sampler, the actual change in thickness is represented by $\Delta L / (\Delta H - \Delta F)$, where ΔF is the change in downward deflection of the strata at the

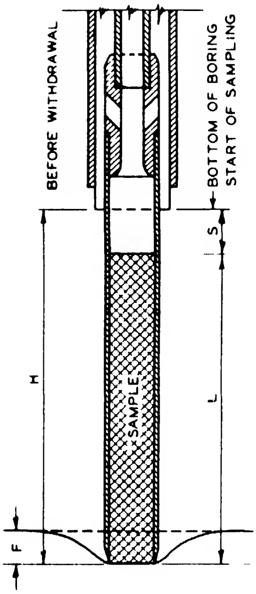


INSIDE CLEARANCE $C_i = \dfrac{D_s - D_e}{D_e}$ CONTROLS INSIDE FRICTION

OUTSIDE CLEARANCE $C_o = \dfrac{D_w - D_t}{D_t}$ CONTROLS OUTSIDE FRICTION

AREA OR KERF RATIO $C_a = \dfrac{D_w^2 - D_e^2}{D_e^2}$ $\dfrac{\text{VOLUME OF DISPLACED SOIL}}{\text{VOLUME OF SAMPLE}}$





H = DEPTH OF PENETRATION = DISTANCE ORIGINAL BOTTOM OF BORE HOLE TO CUTTING EDGE OF SAMPLER

L = ORIGINAL LENGTH OF SAMPLE = DISTANCE TOP OF SAMPLE TO CUTTING EDGE OF SAMPLER BEFORE WITHDRAWAL

L_g = GROSS LENGTH OF SAMPLE = DISTANCE TOP OF SAMPLE TO CUTTING EDGE OF SAMPLER AFTER WITHDRAWAL

L_n = NET LENGTH OF SAMPLE = DISTANCE TOP TO BOTTOM OF SAMPLE AFTER TRIMMING FOR SEALING

L_t = NET LENGTH OF SAMPLING TUBE = INSIDE DISTANCE FROM CUTTING EDGE TO SAMPLE HEAD

L/H = TOTAL RECOVERY RATIO

$\Delta L/\Delta H$ = SPECIFIC RECOVERY RATIO

L_g/H = GROSS RECOVERY RATIO

L_n/H = NET RECOVERY RATIO

F = DEFLECTION OF SOIL AT CUTTING EDGE

$\dfrac{L}{H-F}$ = TRUE TOTAL RECOVERY RATIO

$H_s = L_s$ = SAFE PENETRATION OR SAFE LENGTH OF SAMPLE – MAXIMUM PENETRATION FOR WHICH $\Delta L = \Delta H$ AND $L = H$ CAN BE MAINTAINED = MAXIMUM LENGTH OF UNDISTURBED SAMPLE

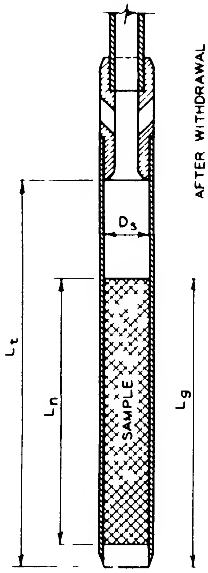
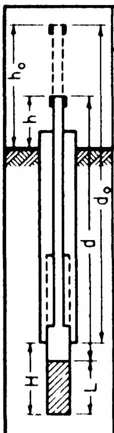


FIG 97-A – CHARACTERISTIC DIMENSIONS, MEASUREMENTS AND RATIOS IN DRIVE SAMPLING



$H = h_o - h$

$L = d_o - d$

$r = \dfrac{\Delta L}{\Delta H} \times 100$

h	d	H	L	ΔH	ΔL	r	H_m
120 0	240 0	0	0	4	4 2	105	2
116 0	235 8	4	4 2	4	4 6	115	6
112 0	231 2	8	8 8	4	4 8	120	10
108 0	228 4	12	13 6	4	4 9	122 5	14
104 0	221 5	16	18 5	4	4 8	120	18
100 0	216 7	20	23 3	4	4 7	117 5	22
98 0	212 0	24	28 0	4	4 4	110	26
92 0	207 8	26	32 4	4	4 0	100	30
88 0	203 8	32	38 4	4	3 4	85	34
84 0	200 2	38	39 8	4	2 7	67 5	38
80 0	197 5	40	42 5	4	2 0	50	42
78 0	195 5	44	44 5	4	1 5	37 5	46
72 0	194 0	48	46 0	4	1 2	30	50
68 0	192 8	52	47 2	4	1 1	27 5	54
64 0	191 7	56	48 3	4	1 2	30	58
80 0	190 5	80	49 5	4	1 6	40	62
56 0	188 9	64	51 1	4	1 8	45	88
52 0	187 1	68	52 9	4	1 6	40	70
48 0	185 5	72	54 5	4	1 2	30	74
44 0	184 3	76	55 7	4	0 9	22 5	78
40 0	183 4	80	56 6	4	0 6	15	82
36 0	182 8	84	57 2	4	0 4	10	88
32 0	182 4	88	57 6	4	0 2	5	90
28 0	182 2	92	57 8	4	0 1	2 5	94
24 0	182 1	98	57 9	4	0 0	0	98
20 0	182 1	100	57 9	4	0 0	0	102
16 0	182 1	104	57 9				

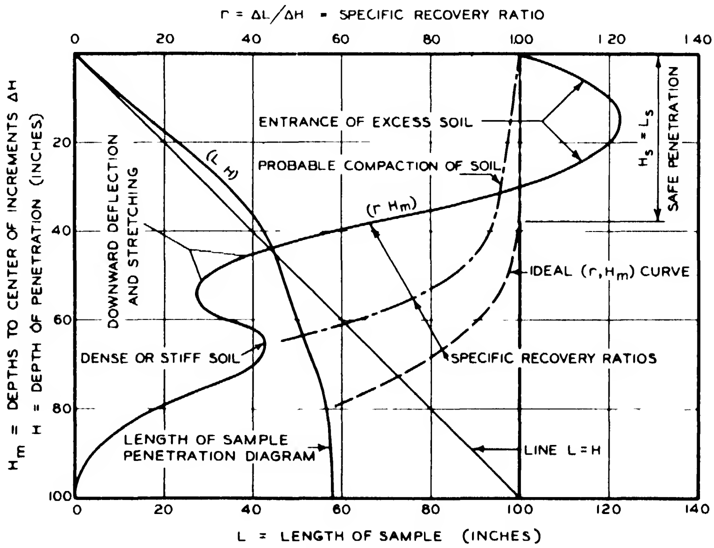


FIG 97-B – TYPICAL RECOVERY RATIO CURVES

cutting edge during the penetration increment ΔH

The first determination of corresponding values of H and L during advance of the sampler was made by **Burkhardt (307, 505)** in exploration and sampling by means of the "Pile Boring Method", described in Section 2 17, see also **Fehlmann (522, 523), Kranz (531), and Wegenstein (356).** A method of making measurements without removing the drive cap is shown in Fig 98A The data obtained may be used as shown in Fig 98B to correct the soil profile, indicated by the sample, for a change in thickness of the various strata during sampling However, the downward deflection of the soil layers before they enter the sampler is not taken into consideration, and the corrected thickness of the individual strata may in certain cases vary materially from the true thickness

In some experiments for the Committee on Sampling and Testing, corresponding values of H and L were determined by direct plumbing through the drill rod These values are plotted as the penetration curve (L,H) in Fig 97B The specific recovery ratio, $r = \Delta L / \Delta H$, is computed for each pair of increments and plotted as a function of the average depth of penetration, H_m, for the increment In the example shown in Fig 97B, the penetration curve (L,H) intersects the line (L = H) at H = 42 in , if the penetration had been stopped at this depth, the total recovery ratio would be 100 percent However, as shown by the specific recovery ratio curve (r, H_m), the thickness of the strata in the upper part of the sample is increased to 122 percent, whereas the strata in the lower part of the sample are reduced through deflection and stretching to 40 percent of their original thickness

The increment lengths of sample ΔL, cannot be determined by plumbing through the drill rod when the sampler is forced into the soil in a continuous, fast motion When the soil is uniformly stratified and samples are taken close to the ground surface, the original thickness of the strata may be determined by means of samples taken in a test pit excavated close to the bore hole Such samples can be obtained by pushing a U-shaped trough or tray of sheet metal into the wall of the test pit, Fig 98C, and are called tray samples Corresponding values of ΔH and ΔL are then determined by direct comparison of the tray samples with those obtained with the drive sampler, taking into consideration possible variations in shrinkage When ΔH is determined from tray samples, it represents the original thickness of the strata, and the specific recovery ratio indicates the true change in thickness of the strata during the sampling This method was first used by **Piggot (727)** in experiments to determine the probable change in thickness of strata in core samples from the ocean bottom

The above mentioned methods for determination of specific recovery ratios are relatively cumbersome and cannot always be used The recording apparatus shown in Fig 98D was therefore developed and used during the last stages of the research A thin piston with a light rod rests on and moves with the top of the sample A scale rod with a narrow strip of paper is attached to the top of the piston rod, and a trigger mechanism with a pencil is fastened to the top of the drill rod and is

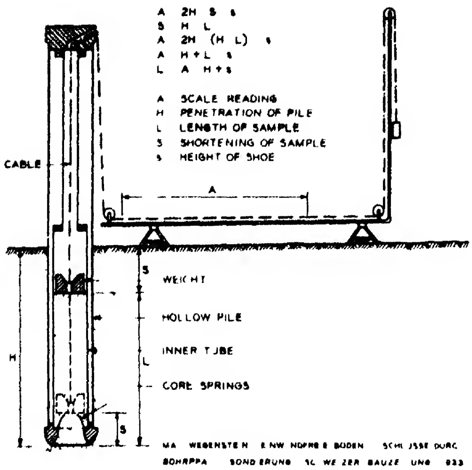


FIG 98-A - FIELD MEASUREMENT OF SAMPLE LENGTH

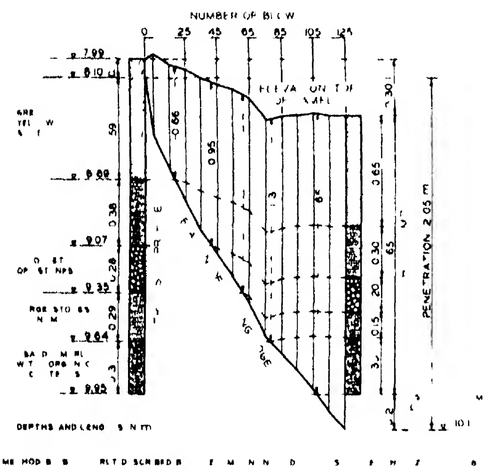
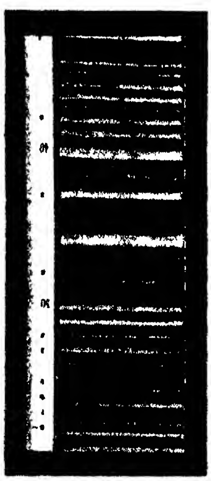


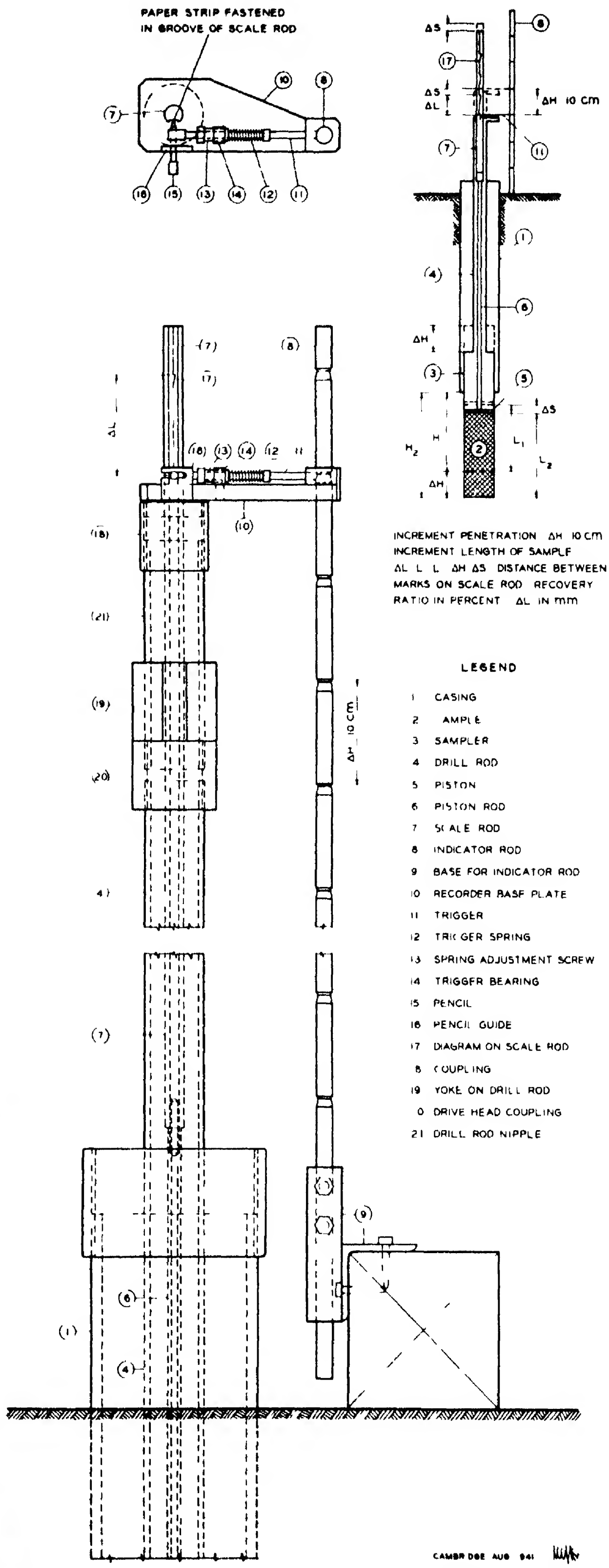
FIG 98 B - CORRECTION OF APPARENT SOIL PROFILE

TRAYS IN TEST PIT



TRAY SAMPLE

FIG 98-C - TRAY SAMPLING



APPARATUS FOR RECORDING SPECIFIC RECOVERY RATIOS

FIG 98-D

actuated by notches in the stationary indicator rod For each 10 cm increase in penetration, the pencil makes an offset mark on the paper strip, and the distance between these marks is the corresponding increase in length of sample When this distance is measured in mm, it indicates directly the specific recovery ratio in percent, and it can be determined even before withdrawal of the sampler A slightly different mechanical recorder has been developed by **Emery and Dietz** (705), and an apparatus with electrical recording of increment sample lengths was built by the Waterways Experiment Station in Vicksburg and described by **K. E. Fields** (136).

An evident requirement for an undisturbed sample is that the specific recovery ratio must be equal to unity or, taking into consideration the above mentioned influence of the inside clearance, not less than $(1 - 2C_1)$ When entrance of excess soil is prevented, it is sufficient that the total recovery ratio be between 1 00 and $(1 - 2C_1)$

4.8 Principal Dimensions of Drive Samplers

The principal dimensions of a drive sampler and certain ratios between these dimensions are defined in Fig 97A, and their optimum values, as far as they have been determined during the research and by practical experience, are discussed in this section

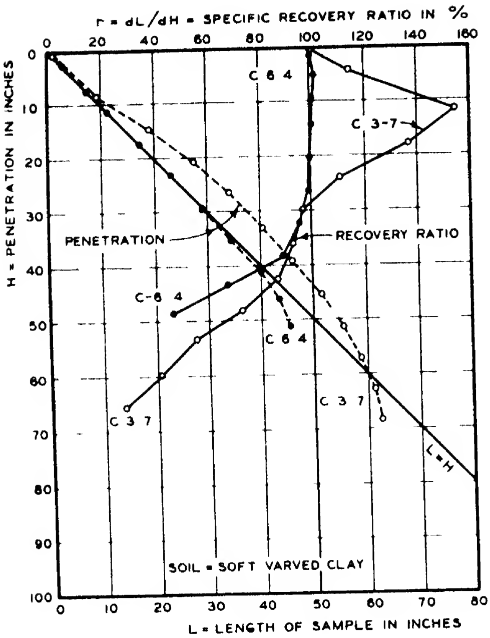
Area ratio.- The annular area, $A_w = \frac{\pi}{4}(D_w^2 - D_e^2)$, not to be confused with the rather indefinite area, A_p, in Fig 88, represents the amount of soil which is displaced when the sampler is forced into the ground The ratio between A_w and the area, $A_e = \frac{\pi}{4} D_e^2$, enclosed by the cutting edge will be called the

$$\text{Kerf or Area Ratio, } C_a = \frac{D_w^2 - D_e^2}{D_e^2}$$

and is approximately equal to the ratio between the volume of displaced soil and the volume of the sample The penetration resistance of the sampler, the possibility of entrance of excess soil, and danger of disturbance of the sample all increase with increasing area ratio

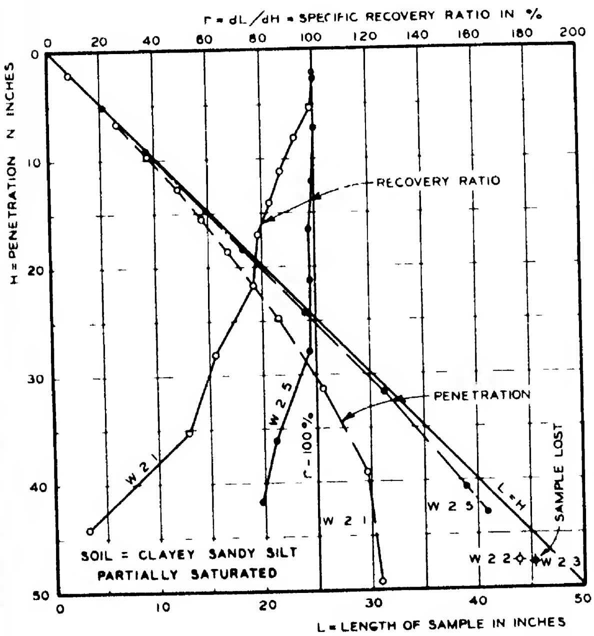
As shown in Fig 99, the entrance of excess soil and the distortions of the soil layers are very small for a sampler with an area ratio of about 10 percent but very large, with specific recovery ratios up to 154 percent, for a sampler with the same inside diameter and an area ratio of 79 percent A large entrance of excess soil is also indicated by some of the recovery ratio curves and photographs shown in Fig 107A and B. Specific recovery ratios up to 125 percent were observed for samplers with an inside diameter of about 4-3/4 in and area ratios of 40 to 45 percent For equal area ratios and type of soil, the entrance of excess soil increases with increasing diameter of the sampler and with increasing depth below the ground surface The entrance of excess soil is large for soft and plastic soils and small

C-3-7 C-6-4



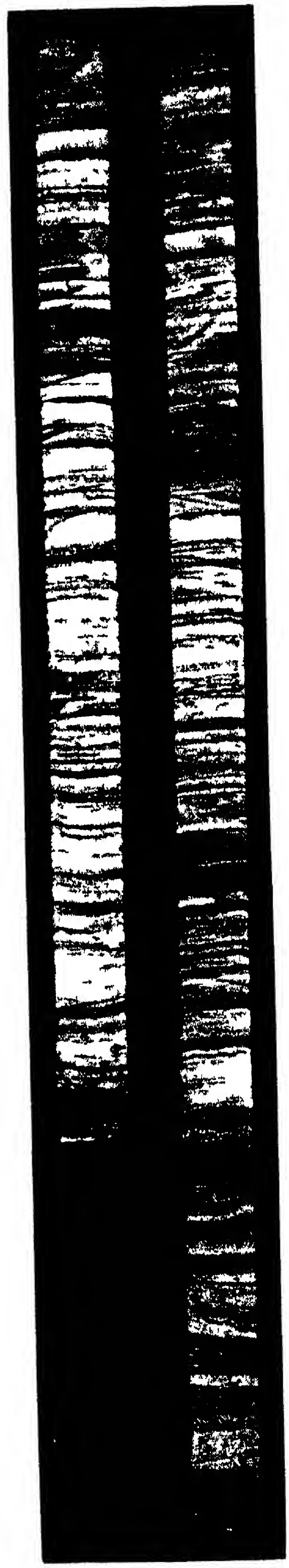
SAMPLER AND TEST	PIGGOT C-3-7	SHELBY TUBING, C 6 4
INSIDE DIAMETER	1 913	1 906
AREA RATIO	79%	10%
INSIDE CLEARANCE	2 7%	1 2%
DRIVING METHOD	SLOW JACKING	SLOW JACKING

FIG 99 - INFLUENCE OF AREA RATIO



2 PIGGOT SAMPLER	TEST NO	AREA RATIO	INSIDE CLEARANCE	
OUTSIDE DIAMETER = 2 50	W 2-1	71%	0%	○
INSIDE DIAMETER = 1 93	W 2-2	75%	1 8%	✧
OUTSIDE CLEARANCE = 0%	W-2-3	87%	4 8%	✦
DRIVING BY SHOOTING	W-2-5	75%	1 8%	•

FIG 100 - INFLUENCE OF INSIDE CLEARANCE



W-2-1 W-2-5

for cohesionless soils, nevertheless, it is possible that the disturbance caused by soil displacement is greatest for cohesionless soils and for stiff and brittle soils, since the strain producing failure of these soils is very small

In the experiments showing a large entrance of excess soil the samplers were generally forced into the soil by slow, intermittent jacking, which promotes plastic displacements and entrance of excess soil, whereas a high velocity of penetration greatly decreases and may nearly eliminate entrance of excess soil, see Section 4 9 The influence of a large area ratio can also be counteracted by giving the cutting edge a very flat taper, Section 4 11, and entrance of excess soil can be completely prevented by use of a stationary piston, Section 4 12 However, an amount of soil corresponding to the area ratio must be displaced in any case, and it is an open question whether either a high velocity of penetration or the use of a piston will prevent disturbance of the soil in the vicinity of the cutting edge and before it enters the sampler

The allowable area ratio for samplers intended for obtaining undisturbed samples depends on the diameter, design, and method of operation of the sampler It is evident that it should be reduced to the minimum consistent with the structural strength of the sampler The area ratio should preferably be less than 10 percent, but it is possible that greater area ratios can be tolerated when the sampler is provided with a stationary piston and/or a cutting edge having a very small angle of taper

Inside clearance.- As indicated in Section 4 6, the inside wall friction is one of the principal causes of disturbance of the sample, and it definitely limits the length of sample which can be obtained in a single operation The inside wall friction can be reduced by providing the sampling tube with an interior surface having a low coefficient of friction and by making the diameter of the cutting edge, D_e, slightly smaller than the inside diameter of the sampling tube or liner, D_s The inside clearance thereby provided is expressed by the

$$\text{Inside Clearance Ratio, } C_i = \frac{D_s - D_e}{D_e}$$

The soil is under great stress as it enters the sampler and has a tendency to lateral expansion. The inside clearance should be large enough to allow a part of the lateral expansion to take place, but it should not be so large that it permits excessive deformations and causes disturbance of the sample, or so that it eliminates inside wall friction, thereby causing loss of the sample during withdrawal unless the sampler is provided with a core retainer

The influence of inside clearance on the total and specific recovery ratios and on the disturbance of the sample is clearly seen in Fig 100 and also by comparison of samples P-6 and C-3-3 in Fig 108 and of samples C-6-3 and C-8-2 in Fig. 107. The 2-in brass tubing, used in test series C-8, had no cutting edge but squared-off ends. An annular wedge of soil will then be formed under the blunt end

of the tubing and will act as a cutting edge with an effective diameter $D_e = \frac{1}{2}(D_s - D_t)$, and the theoretical inside clearance is therefore negative The optimum value of the inside clearance ratio varies with the diameter, design, and method of operation of the sampler and, above all, with the character of the soil Further research is needed to determine the optimum values of inside clearance, and the following suggestions are based in part on a relatively small number of experiments in uniform soil and in part on observations during practical sampling operations

Very short samplers for surface and control sampling -- Section 4 20 -- may be used in some soils without any inside clearance, but inside clearance ratios up to 1 0 percent may be required in other soils Medium long samplers used in bore holes require an inside clearance ratio between 0 5 and 3 0 percent according to the character of the soil The optimum inside clearance seems to decrease a little with increasing diameter of the sample, and samplers forced into the soil by hammering or slow jacking require a larger inside clearance than those pushed into the soil in a fast, uninterrupted motion Inside clearance ratios of 5 to 10 percent are often used when the primary object is to obtain very long samples, when large lateral deformations of the sample can be tolerated, and when the sampler is provided with a core retainer

For general practical use an inside clearance ratio of 0 75 to 1 5 percent for long samplers and 0 to 0 5 percent for very short samplers is suggested, but the best results are obtained when the clearance is varied in accordance with the character of the soil Smaller clearances will probably suffice when the sampler is provided with sliding steel foils, see Section 10 5 The commercial tolerance on the inside diameter of standard tubing used for liners or sampling tubes should be taken into consideration

Outside clearance.- Many samplers are provided with a detachable shoe and cutting edge, and the outside diameter of the shoe, D_w, is often made slightly larger than the outside diameter of the sampling tube, D_t, in order to reduce the outside wall friction An

$$\text{Outside Clearance Ratio, } C_o = \frac{D_w - D_t}{D_t},$$

of a few percent may materially decrease the penetration resistance of the sampler in common cohesive soils but not in cohesionless soils It also appears that an outside clearance will increase the length of samples of cohesive soils which can be obtained in a single operation However, systematic experiments have not yet been made to determine the optimum values of the outside clearance ratio in various types of soils or to investigate the influence of the outside clearance on the disturbance of the soil before it enters the sampler Considering that an outside clearance increases the area ratio of the sampler, and pending further investigations, it is suggested that the outside clearance ratio should be zero for samplers used in cohesionless soils and that it should not exceed 2 to 3 percent for samplers used in cohesive soils unless the angle of taper of the cutting edge is very small

Diameter of the sample.- With a properly designed and operated drive sampler it is possible to obtain samples less than 1 in in diameter without any visible distortions or measurable changes in the thickness of the soil layers In spite of this absence of outward signs of disturbance, there is probably some disturbance of the soil structure close to the surface of the sample, see Section 6 9, and the degree of disturbance in the central part of the sample undoubtedly decreases with increasing diameter The degree and extent of a small partial disturbance close to the cylindrical surface of an apparently undisturbed sample have not yet been adequately investigated, and the diameter of the sample is primarily determined by laboratory requirements and practical considerations, see Section 1 10

Length of sample.- The length of sample to be taken should be governed by the "safe penetration" or depth of penetration at which a downward deflection of the soil layers below the sampler starts This depth is approximately equal to the penetration, H_s in Fig 97B, at which a specific recovery ratio -- or a total recovery ratio when entrance of excess soil is prevented -- of 100 or slightly less than 100 percent can be maintained The corresponding "safe length of sample", L_s, is the maximum length of "undisturbed" sample which can be obtained in a single operation

The safe length, L_s, depends on so many factors that it is very difficult to formulate definite rules for estimating it In sampling experiments and practical sampling operations with drive samplers having 1 in to 5 in inside diameter, D_s, it was found that for a given type of soil, sampler, and method of operation the length-diameter ratio, L_s / D_s, was fairly constant although it tends to decrease with increasing diameter This ratio increases with increasing inside clearance ratio, speed and uniformity of penetration, and depth below the ground surface, and it varies over a very wide range with the character of the soil

For a properly designed and operated drive sampler with an inside diameter of about 2 to 3 in , it was found that the range of values for L_s can be expressed approximately by

Dense to Loose Cohesionless Soils, $L_s = (5 \text{ to } 10)\ D_s$
Stiff to Very Soft Cohesive Soils, $L_s = (10 \text{ to } 20)\ D_s$

Smaller values of L_s can be expected for samplers of large diameter and greater values for samplers of very small diameter Greater lengths may also be obtained when the speed of penetration is very high, when samplers with stationary piston are used in very deep bore holes, and when excessive inside clearances are used

The limiting length of the sample -- that is, the length at which a permanent soil cone is formed below the cutting edge and no more soil enters the sampler -- is much greater than L_s, but the soil entering the sampler after the safe depth of penetration is exceeded will be seriously disturbed When the detrimental influence of the inside wall friction and adhesion is eliminated, as in the recently developed piston sampler with steel foils, Fig 216, both the safe length and the limiting length of the sample may be many times greater than indicated above

It is advisable, within practical limitations, to utilize fully the safe depth of penetration and, in some cases, even to exceed this depth for a distance of 2 to 3 times the diameter of the sampler, since the lower part of the sample will be disturbed anyway when the sample is separated from the subsoil The penetration must then be varied in accordance with the character of the soil, but with some experience and observation of total or gross recovery ratios, the driller will soon be able to estimate the penetration which should be used in a given type of soil It was formerly customary and there is still a tendency to take rather short samples in order to standardize the sampling operations and to correlate the advance of the bore hole with the standard lengths of drill rods and casing, 5 to 10 ft It should be remembered, however, that the danger of losing the sample and the cost of continuous samples decrease with increasing length of sample and also that the top and bottom sections of the sample usually will be partially disturbed, even when the safe depth of penetration is not exceeded

4.9 Methods of Forcing the Sampler into the Soil

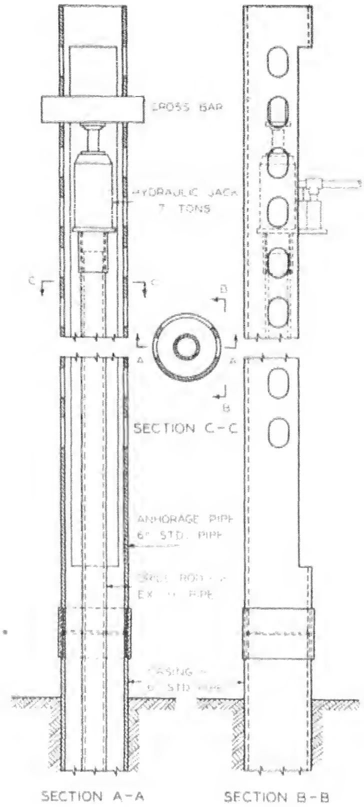
The various methods used to force a drive sampler into the soil may be classified in the following groups

Hammering	Repeated blows of a drop hammer	Intermittent fast motion
Jacking	Levers or short commercial jacks	Intermittent slow motion
Pushing	Steady force, no interruptions	Continuous uniform motion
Single Blow	Blow of a heavy drop hammer	Continuous fast motion
Shooting	Force supplied by explosives	Continuous very fast motion

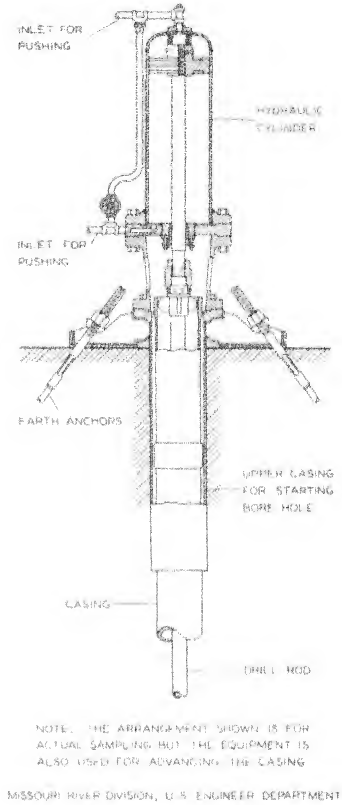
The terms "ramming" and "continuous drive" were used in the preliminary report (107), but it was found that they occasionally caused misunderstandings, therefore they have been replaced with the terms "hammering" and "pushing" In several figures the term "driving method" has been used as the equivalent of the method of forcing the sampler into the soil and may possibly also cause .misunderstanding, but a better short term for this operation has not yet been found

Equipment.- When a sampler is to be forced into the soil by hammering, the drop hammers shown in Fig 22 are commonly used, but gasoline-driven jack hammers are occasionally employed for small-diameter samplers The hammer blows are usually applied to a drive head on top of the drill rod, and a part of the energy will then be absorbed by the drill rod, which also will be subjected to lateral deformations and partial buckling and may impart a rocking motion to the sampler, thereby

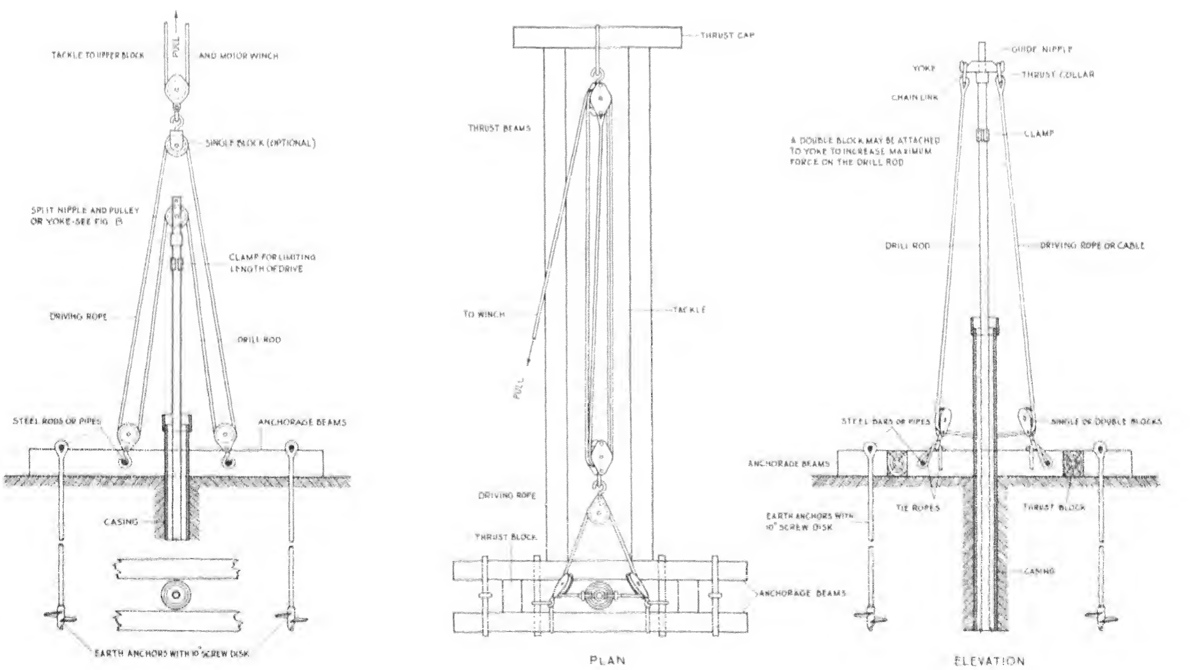
PRYING SAMPLER INTO SOIL
FIG. 101



MOHR JACKING ARRANGEMENT
FIG. 102



MISSOURI HYDRAULIC DRIVE
FIG. 103

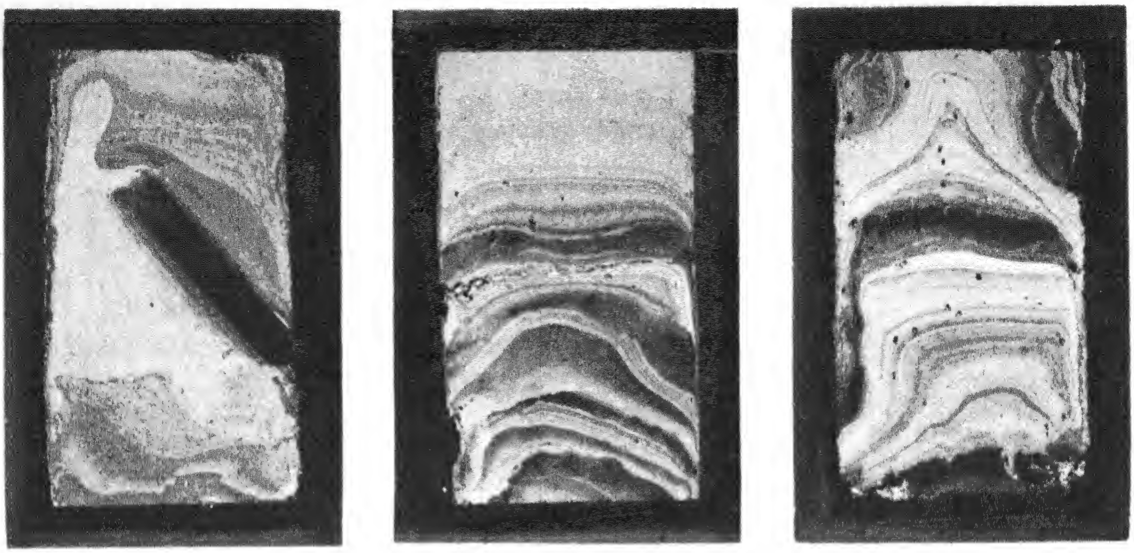


A
VERTICAL PULL

B
HORIZONTAL PULL

FIG. 104 - PUSHING BY BLOCK AND TACKLE

MAY - NOV 1941



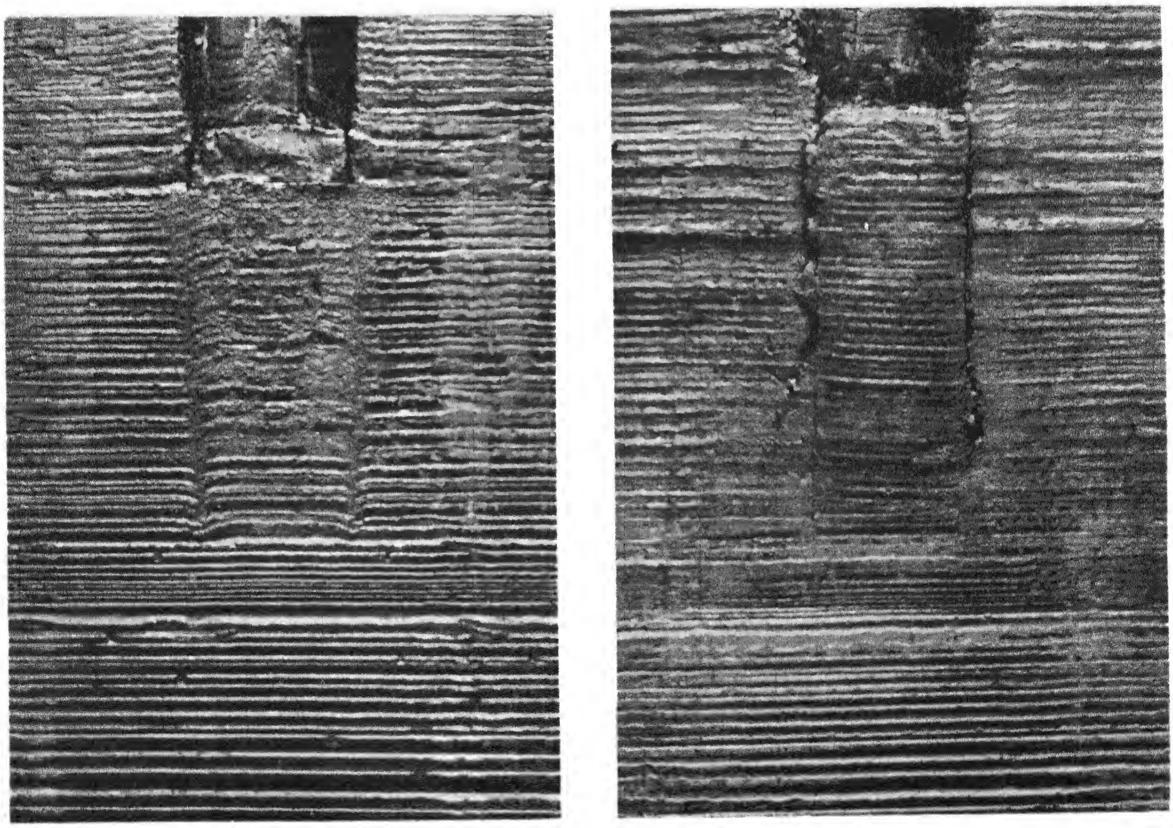
A — TOP OF SAMPLE - IMPROPER CLEANING - MIXED SOIL

B — UPPER HALF - SEGREGATED SAND - DISTORTIONS

C — LOWER HALF - SERIOUS DISTORTIONS - GAS BUBBLES

O.D. SHOE = 3.625" - I. D. LINER = 3.00" - INSIDE CLEARANCE = 2.1 % - OUTSIDE CLEARANCE = 3.6 % - AREA RATIO = 53.5 % - DIAMETER OF VENT = ½"

FIG 105 - SAMPLE TAKEN WITH HEAVY-WALL SAMPLER AND HAMMERING



A - SLOW JACKING

12.5 % SPECIFIC RECOVERY - DISTORTION OF SOIL LAYERS - LATERAL DEFORMATION BY WEIGHT OF SAMPLE - PITTING BY WASH WATER

B - FAST PUSHING

100 % SPECIFIC RECOVERY THROUGHOUT - NO DISTORTION OF SOIL LAYERS - SMALL LATERAL DEFORMATION - NO PITTING BY WASH WATER

O.D. SHOE = 5.625" - I.D. LINER = 4.75" - INSIDE CLEARANCE = 1.3 % - OUTSIDE CLEARANCE = 2.3 % - AREA RATIO = 44 % - SOIL = SOFT VARVED CLAY
LOWER PART OF SAMPLES LOST IN HOLE - PITS EXCAVATED EXPOSING SAMPLES - FACE OF PIT TRIMMED AND WASHED TO SHOW STRATIFICATIONS

FIG. 106 - INFLUENCE OF THE DRIVING METHOD - 4¾" M.I.T. SAMPLER

increasing the disturbance of the sample Greater efficiency is obtained, and irregular motions of the sampler can be decreased, when the sampler is driven by a drill stem and jar, Fig 32, attached directly to the sampler head

Simple arrangements for prying and jacking the sampler into the soil are shown in Fig 101 and 102 These arrangements utilize the casing as anchorage, but special anchorages must be provided when the embedded length of casing is relatively short and the withdrawal resistance is small

Small-diameter samplers maybe pushed into soft soils by the weight of members of the drilling crew, augmented, if necessary, by weights or a drop hammer placed on the drill rod Penetration resistance can be decreased by rotating the sampler during the pushing, but this procedure should not be allowed since it may cause the soil to fail in torsion and become seriously disturbed as it enters the sampler Specially built, long hydraulic jacks, Fig 103, or the hydraulic feed jacks or chain drives on motorized drilling rigs may be used, but to satisfy the requirements of the method of pushing, the stroke should be long enough to complete the drive without re-setting and other interruptions, and the capacity of the oil pump should be large enough to produce a speed of penetration of about 0 5 ft per second

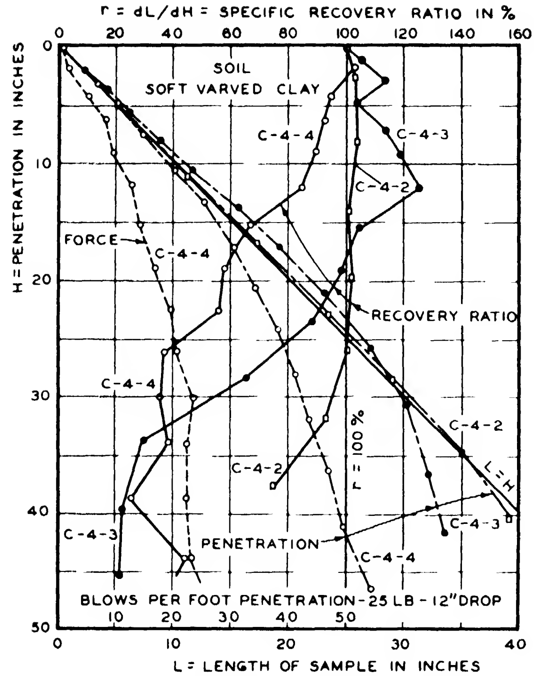
The sampler may also be pushed or pulled down by means of a winch and blocks and tackle This method was first used by Russian engineers, **Sacharova (546)**, who utilized a single pulley and rope, thereby producing an eccentric force on and severe bending of the drill rod. The block and tackle pull-down arrangements shown in Fig 104 were developed during the research and produce a central force on the drill rod The arrangement for a horizontal pull, Fig 104B, has the advantage that the force on the anchors is only half as great as for a vertical pull, Fig 104A, and that the length of the stroke is not limited by the height of the tripod or mast

In several experiments the sampler was forced into the soil by a single blow of a 500-lb hammer dropping 4 to 9 ft The velocity attained during the drop and the force transmitted to the drill rod were decreased to some extent by friction in the blocks and twisting of the ropes In other experiments the sampler was forced into the soil by shooting, using the Piggot coring tube, Fig 259

The various samplers, used in the experiments discussed in the following paragraphs, are described in Part II of this report

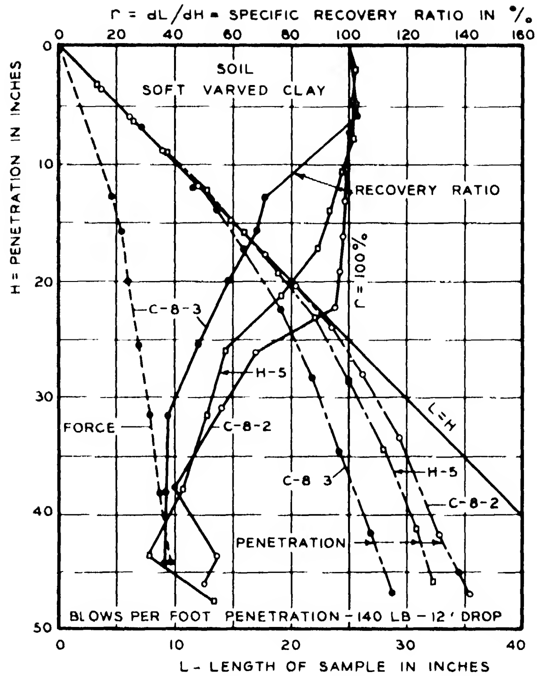
Test data.- Representative examples of photographs and recovery ratio diagrams obtained in the experiments are shown in Fig 105 to 108 Most of the experiments were made in soft varved clay, but the conclusions have been verified substantially by incomplete series of experiments in other types of soil and by observations during practical sampling operations. Nevertheless, on account of the great variations in the physical properties of soils, it is possible that exceptions to these general conclusions may be found.

Fig 105 shows sections of a very seriously disturbed sample. The disturbance is the combined effect of improper cleaning, a large area ratio, a small vent area,



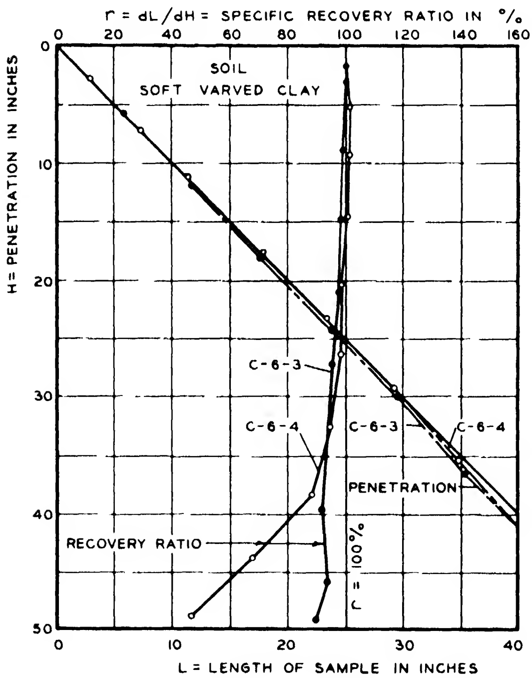
INSIDE DIA OF LINER 0 945" — METHOD OF DRIVING
INSIDE CLEARANCE 5% — ○ TEST C-4-4 = HAMMERING
OUTSIDE CLEARANCE 12 2% — ● TEST C-4-3 = SLOW JACKING
AREA RATIO 147 % — □ TEST C-4-2 = FAST PUSHING

1" PORTER SAMPLER



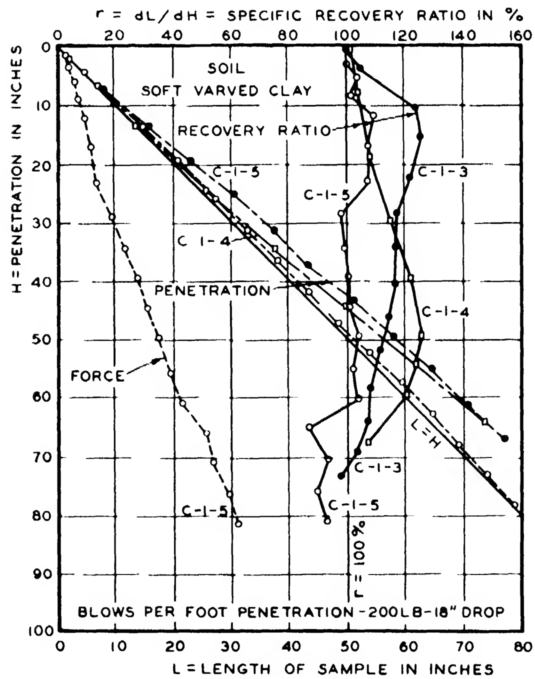
INSIDE DIAMETER 1 93 — METHOD OF DRIVING
INSIDE CLEARANCE -1 6% — ○ TEST C-8-2 - FAST PUSHING
OUTSIDE CLEARANCE 0% — ● TEST C-8-3 = HAMMERING
AREA RATIO 6 6° — □ TEST H-5 = SINGLE BLOW

2" BRASS TUBING



INSIDE DIAMETER 1 93" — METHOD OF DRIVING
INSIDE CLEARANCE 1 2%
OUTSIDE CLEARANCE 0% — ○ TEST C-6-4 = SLOW JACKING
AREA RATIO 10% — ● TEST C-6-3 = FAST PUSHING

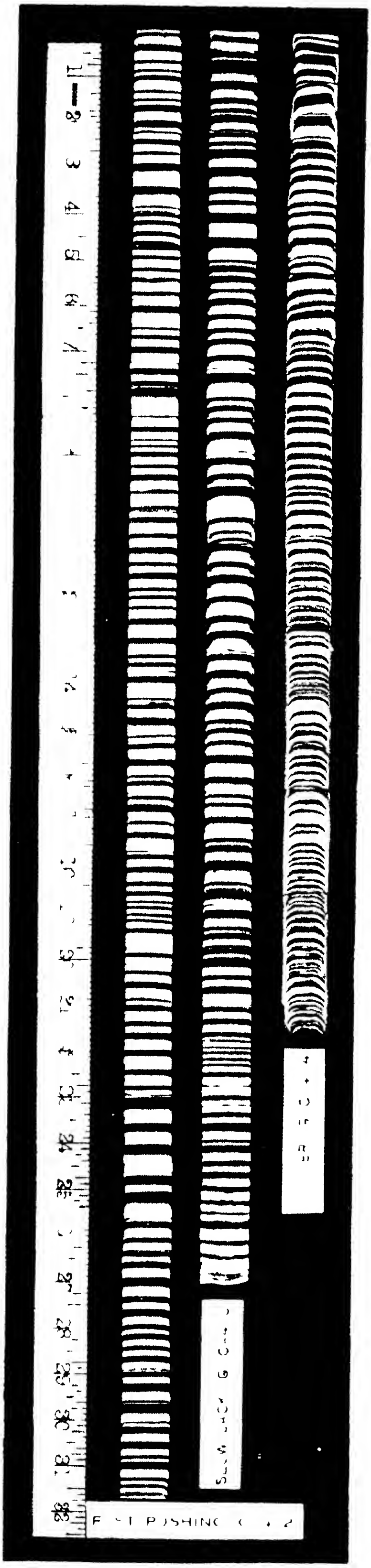
2" STEEL TUBING



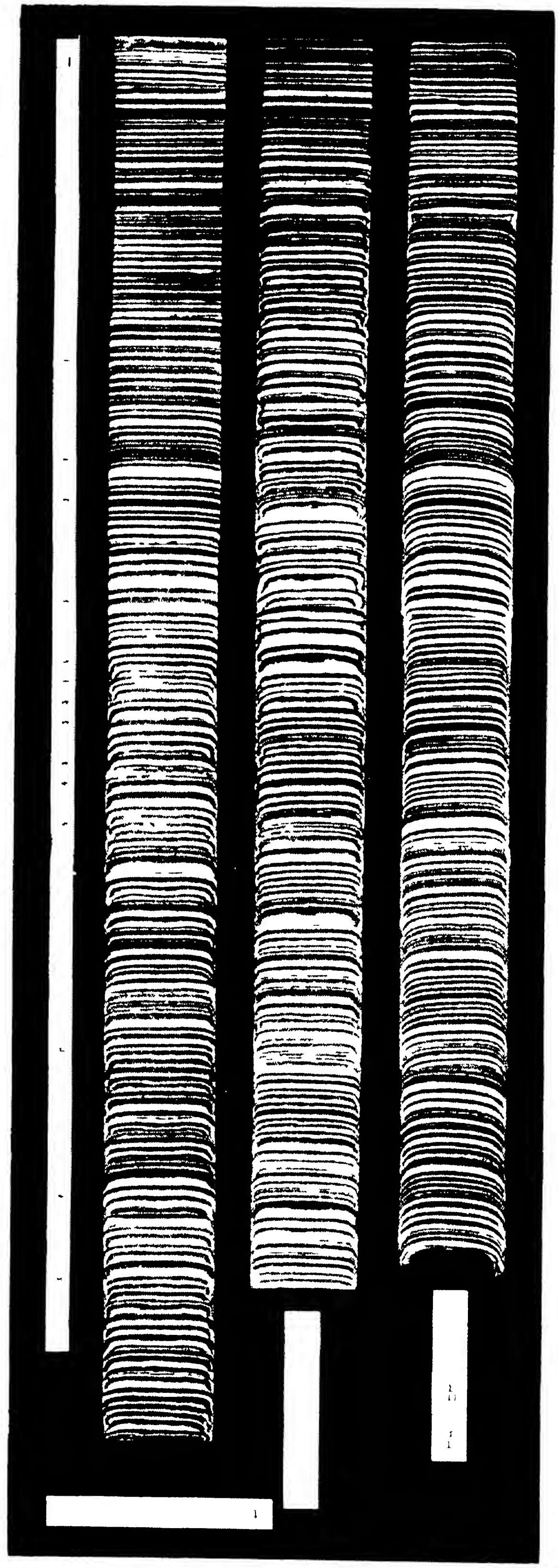
INSIDE DIA OF LINER 4 73" — METHOD OF DRIVING
INSIDE CLEARANCE 2 9% — ○ TEST C-1-5 = HAMMERING
OUTSIDE CLEARANCE 4 6% — ● TEST C-1-3 = SLOW JACKING
AREA RATIO 4 4% — □ TEST C-1-4 = FAST PUSHING

4¾" MOHR SAMPLER

FIG 107-A — INFLUENCE OF THE METHOD OF DRIVING

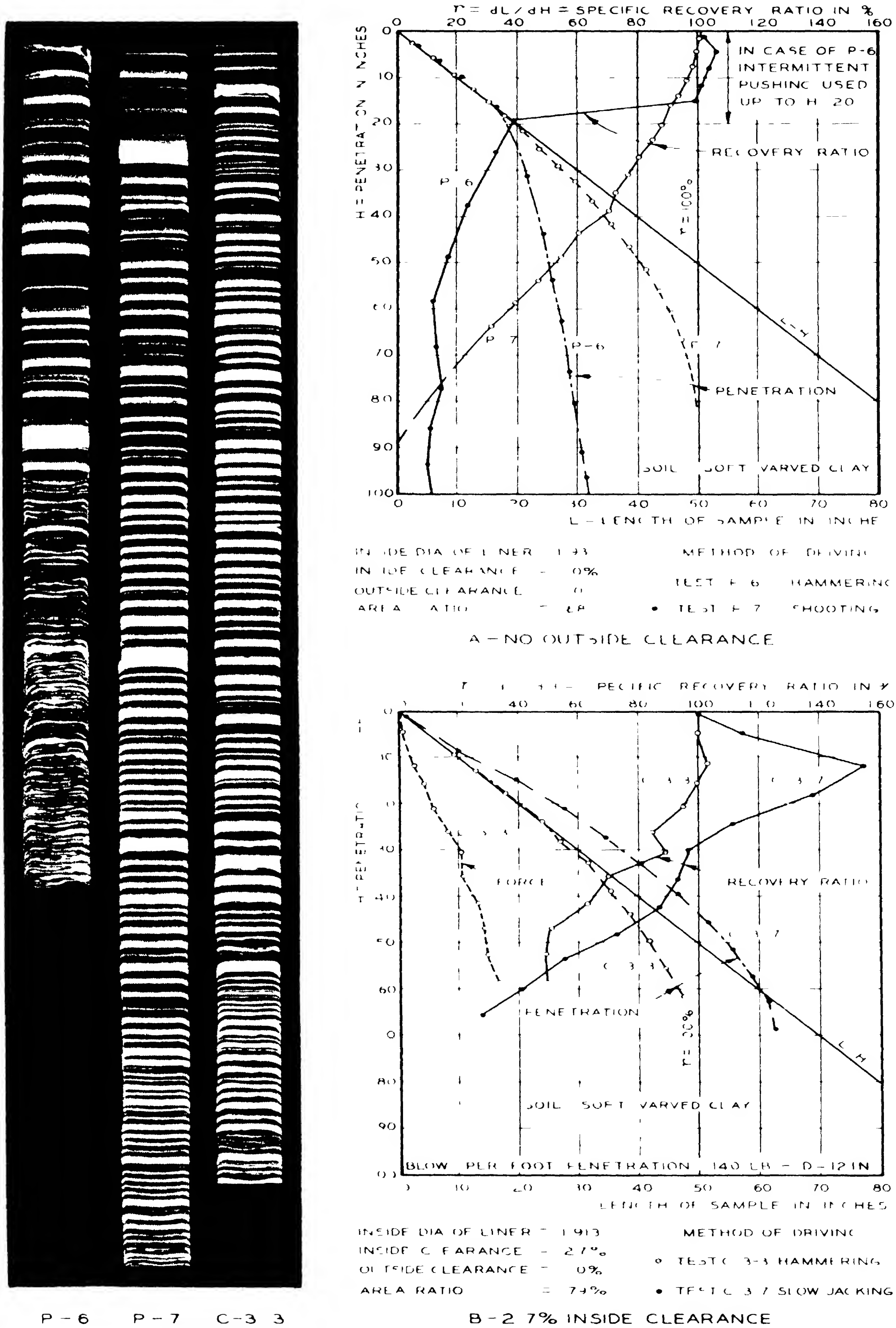


1" PORTER SAMPLER



4¾' MOHR SAMPLER

FIG 107-B – INFLUENCE OF THE METHOD OF DRIVING



INFLUENCE OF THE METHOD OF DRIVING - PIGGOT SAMPLER

FIG 108

and of forcing the sampler into the soil by hammering The small vent area and the momentary high velocities of penetration during hammering cause formation of very large hydrostatic pressures over the sample The black dots represent bubbles of gas which have expanded or been released from solution in the pore water when the over-all stresses in the sample were reduced after withdrawal of the sampler

Fig 106 shows the results of tests with the M I T sampler provided with a Providence shoe, Fig 191 and 193 The lower parts of the two samples were lost during the withdrawal and later exposed by excavation and photographed in situ The walls of the pits were trimmed and washed to bring out the stratifications in the samples and surrounding soil The penetration of the sampler is only 22 in , which is too short to allow full development of the distortions Nevertheless, the sample obtained by slow jacking shows prominent convex distortions, corresponding to a maximum specific recovery ratio of 125 percent, and the soil has been subjected to a great loss in strength and was eroded during the washing of the trimmed face of the pit On the other hand, the sample obtained by fast pushing has 100 percent specific recovery ratios throughout and no visible distortions, and the sample appeared as firm as the surrounding soil However, these samples were taken very close to the ground surface, and when the same sampler later was used in a 50-ft deep bore hole and in similar soil, even fast pushing could not prevent considerable entrance of excess soil

Fig 107A and B show the results of tests with a 1-in Porter sampler, Fig 218, 2-in thin-wall samplers of brass and steel tubing, Fig 180-182, and a 4-3/4-in Mohr sampler, Fig 239 As already indicated on page 107, the brass tubing had no cutting edge but squared-off ends and theoretically a negative inside clearance. All samples were taken very close to the ground surface, and it should be borne in mind that the danger of entrance of excess soil and also the limiting length of the sample increase with increasing depth below the surface.

The Porter sampler was used without a piston in order to eliminate the effect of restricted vents and excess pressures over the sample in the tests to determine the influence of various methods of driving A long sample with very little distortion of the soil layers was obtained by fast pushing, but there was a circumferential void between the upper part of the sample and the liner, indicating excessive inside clearance This sampler has a very large area ratio, which probably will cause entrance of excess soil when samples are taken at an appreciable depth below the ground surface and the sampler is jacked or pushed into the soil

The Mohr sampler was provided with flap valves without fillets between the flaps The recesses in the walls of the shoe, thereby created, greatly increased the distortion of the soil layers -- see photograph in Fig 239 -- and obscured the effect of the various methods of driving The sample obtained by hammering, C-1-5, has specific recovery ratios close to 100 percent but greater distortions than the sample obtained by fast pushing, C-1-4 It should be noted that maximum entrance of excess soil occurs at a greater depth of penetration for fast pushing than for slow jacking.

Fig 108 shows the results of four tests with the Piggot coring tube, Fig 259, but the photograph contains only three of the four samples, since that of sample C-3-7 already is shown in Fig 99 Photographs of some sections of samples C-3-7 and P-7 are shown to a larger scale of reproduction in Fig 89A and B and Fig 90A

In all the above mentioned tests the average speed of penetration for hammering and slow jacking was greatly decreased by the time required for measurement of recovery ratios and re-setting of drive heads and jacks and it varied between 0 6 and 1 2 in per minute, for fast pushing the speed of penetration varied between 0 5 and 1 0 ft per second, and it was roughly estimated to be between 25 and 50 ft per second in case of shooting

Conclusions.- As shown by the results of the above mentioned tests, the speed and continuity of motion with which the sampler is forced into the soil have a great influence on the length and degree of disturbance of the sample obtained The effects of the various methods of forcing the sampler into the soil may be summarized as follows

Hammering practically eliminates entrance of excess soil during the first part of the drive, even when the area ratio of the sampler is large, but hammering also reduces the effectiveness of the inside clearance and tends to produce short and distorted samples of cohesive soils Vibrations produced by hammering may cause volume changes and disturbance of samples of cohesionless soils When there is water in the sampler, the high velocities of penetration, momentarily attained, produce excessive hydrostatic pressures over the sample unless very large and streamlined vents are provided in the sampler head With possible exception of some stiff and tough cohesive soils, hammering will generally cause partial to serious disturbance of the sample Hammering may be required to force a sampler into hard or dense and coarse soils, but it should not be used when undisturbed samples are desired of soft or loose soils

Slow jacking allows plastic deformations and volume changes to take place It promotes entrance of excess soil and development of wall friction and adhesion with consequent increase of penetration resistance and distortion of the soil layers It produces shorter samples of cohesionless soils than any other method of forcing the sampler into the soil Fairly satisfactory samples of not too soft cohesive soils may be obtained with slow jacking, provided thin-wall samplers are used but distortions and shear failures may occur after a relatively short penetration

Fast pushing, or a fairly uniform and uninterrupted advance at 0 5 to 1 0 ft per second, produces longer and less disturbed samples than either hammering or slow jacking Fast pushing can therefore be recommended for general use in obtaining undisturbed samples, but it is emphasized that the sampler must not be rotated nor its downward movement interrupted Rotation may cause failure of the soil as it enters the sampler, and an interruption of the advance of the sampler allows development of wall friction and adhesion, increases penetration resistance, and may

cause distortion of the soil layers before and after they enter the sampler and a decrease of the length of the sample.

A single heavy blow or shooting may produce even longer and less disturbed samples than fast pushing, although the influence of the impact and high velocities has not yet been adequately investigated. The high velocities attained require very large vents in the sampler, especially when water must be forced out through the vents during the drive. In this case, the vents should be streamlined and have an area equal to the cross-sectional area of the sample.

4.10 Penetration Resistance of Drive Samplers

Depending upon the method used to force a drive sampler into the soil, its penetration resistance may be determined as a dynamic or static resistance. Determination of this resistance corresponds to a sounding test and provides advance information on the strength or density of the soil at very little extra cost.

Determination of the dynamic penetration resistance as a regular procedure in exploratory boring and sampling was initiated in this country about 1927 by **H. A. Mohr**, and the original procedure and type of equipment is still used by the Gow Division of the **Raymond Concrete Pile Company.** Two-inch casing is used and kept filled with water, and the sampler is simply a section of one-inch Extra Heavy Pipe, also used as drill rod. The hammer, Fig. 22-C, weighs approximately 140 lb, and its average height of fall is 30 in. The penetration resistance is expressed as the number of blows required to drive the sampler one foot into the soil, measured from the depth to which the sampler sinks under the weight of the drill rod. Other divisions of the **Raymond Concrete Pile Company** use the same weight and drop of the hammer but the sampler shown in Fig. 178. Furthermore, the sampler is first forced about 6 in. into the soil in order to decrease the influence of the disturbed zone below the bottom of the bore hole, and the number of blows required to advance the sampler an additional 12 in. is used as a measure of the penetration resistance.

Examples of proposed correlations between the consistency or relative density of soils and the dynamic penetration resistance of samplers are shown in simplified form in Table 6. The first of these is by **H. A. Mohr (A-23)**, the second is by **Terzaghi and Peck** (246), the third is contained in the New York City Piling Code and is cited in a review by **Thornley (A-36)**, and the fourth is part of a large table of correlations by the **New England Division, Corps of Engineers.** Large differences in both designations and number of blows are apparent. All authors emphasize that the correlations are qualitative rather than quantitative in nature and are influenced by the character of the soil, such as grain-size distribution, permeability, and degree of saturation. In general, the coarser cohesionless soils require more blows and the finer materials fewer blows than indicated in the table, and classifications should be based not only on the penetration resistance but also on a careful examination of the samples obtained. The extra work required to determine the penetration resistance is small compared to the value of the data obtained, but it should be realized that these

data only provide a rough, not always dependable indication of the consistency or relative density of the soil, and that the penetration resistance depends on many other factors discussed below in groups pertaining to equipment, procedure, and soil conditions.

TABLE 6 - SOME PROPOSED CORRELATIONS OF PENETRATION RESISTANCE AND SOIL PROPERTIES

Extreme caution should be exercised in using any table of correlations outside the areas or for other conditions than those for which the correlations have been established, even then large deviations from such correlations have been reported. The penetration resistance depends not only on dimensions of the equipment and the consistency or relative density of the soil, but it may also vary with the method of operation, depth below ground surface, and other factors not yet fully investigated.

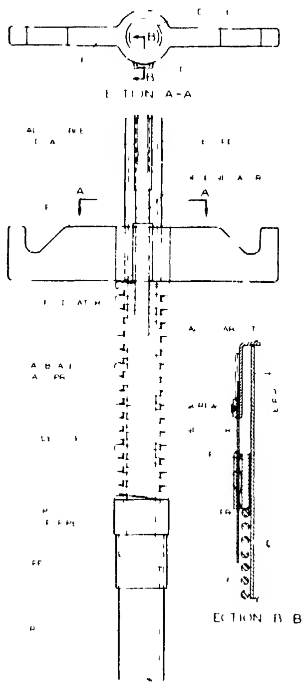
AUTHOR	H A MOHR		TERZAGHI AND PECK		NEW YORK CITY CODE		NEW ENGLAND DIV , C E	
SAMPLER	1-in Extra Heavy Pipe 1 315-in OD 0 957-in ID		Raymond - Fig 178 2 0-in OD, 1 375-in ID		2 50-in OD		3 00-in OD	
HAMMER	140 lb ±, 30-in ± Fall		140 lb, 30-in Fall		300 lb 18-in Fall		300 lb, 18-in Fall	
SOIL	Designation	Blows/Ft	Designation	Blows/Ft	Designation	Blows/Ft	Designation	Blows/Ft
SAND and SILT (Rel Density)	Loose	Less 9	Very loose	Less 4	Loose	0 - 15	Very loose	Less 8
			Loose	4 - 10			Loose	8 - 16
	Firm	9 - 13	Medium	10 - 30	Compact	16 - 50	Medium	16 - 55
	Hard	14 - 49	Dense	30 - 50			Compact	55 - 110
	Hardpan	Over 50	Very dense	Over 50	Very compact	Over 50	Very compact	Over 110
CLAY (Consistency)			Very soft	Less 2	Very soft	0 - 2	Very soft	Less 8
	Soft	Less 5	Soft	2 - 4	Soft	3 - 10	Soft	8 - 16
	Medium	5 - 10	Medium	4 - 8			Medium stiff	16 - 55
			Stiff	8 - 15	Stiff	11 - 30	Stiff to Medium hard	55 - 110
	Hard	11 - 30	Very stiff	15 - 30				
			Hard	Over 30	Hard	Over 30	Very hard	Over 110

The factors related to equipment include diameter and area ratio of the sampler, smoothness of outside and inside surfaces, shape of cutting edge and clearances, area and shape of vents, weight and height of fall of hammer, size and length of drill rod, and diameter of the casing in relation to that of the sampler. The influence of the vent area can be very great, and the penetration resistance of a sampler with small vents and filled with water may be several times that of the same sampler when it is operated in a dry bore hole or the water is forced out by compressed air, Fernau (123). The factors pertaining to procedure are methods of advancing and cleaning the bore hole, relative depths of boring and edge of casing, time interval between boring and sampling, spacing of samples, and depth of penetration of the sampler. The penetration resistance will be increased when the soil has been compacted by previous sampling or advancing the casing ahead of the boring, and it will be decreased when the boring is improperly cleaned and when actual failure and flow of soil into the casing occur.

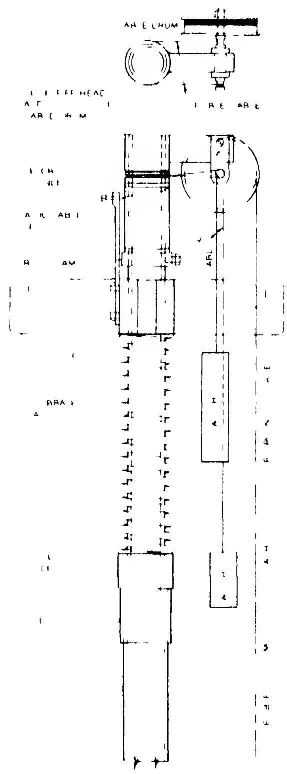
Standardization of equipment and procedure, insofar as possible, would permit most of the above mentioned factors to be taken into consideration in the correlations, but even then considerable scattering of the results is to be expected. In addition to the strength and relative density of the soil, the penetration resistance may also be influenced by the permeability and degree of saturation, by size, grading, and angularity of the grains of cohesionless soils, and by sensitivity to disturbance of cohesive soils. Furthermore, recent investigations by the Waterways Experiment

Station (A-42) indicate that in massive sand deposits the penetration resistance may be influenced by the water levels in ground and boring, and that it is subject to great irregularities but often with a definite tendency to increase with increasing depth of the boring, particularly in medium and dense sand. These observations correspond to those made during sounding tests in sand, and they indicate that the influence of the depth below ground surface in some cases must be taken into consideration in the correlations.

When the sampler is forced into the soil by means of a hydraulic jack or the hydraulic feed of a rotary drilling rig, Fig. 37, the static penetration resistance is easily determined by a pressure gage on the oil line or the cylinders, and a gas or steam engine indicator may be used to record complete resistance diagrams. Simple, improvised spring dynamometers used in combination with direct pushing or a block and tackle arrangement, Fig. 104, during the research are shown in Fig. 109 and 110. The static penetration resistance depends on most of the factors enumerated for the dynamic resistance, but the weight of the drill rod is easily taken into consideration, and the influence of the vent area is relatively small at the usual speeds of penetration. However, the speed of penetration itself may exert considerable influence on the resistance and should therefore be kept constant.

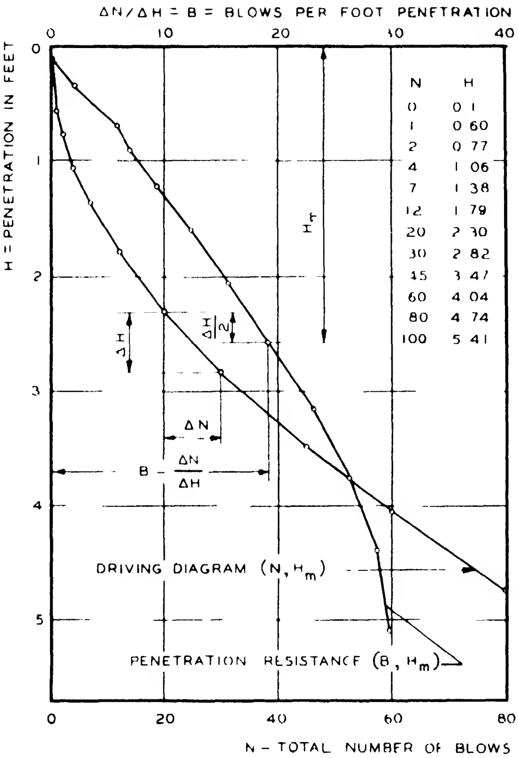


SPRING DYNAMOMETER
MAX FORCE INDICATOR
FIG 109



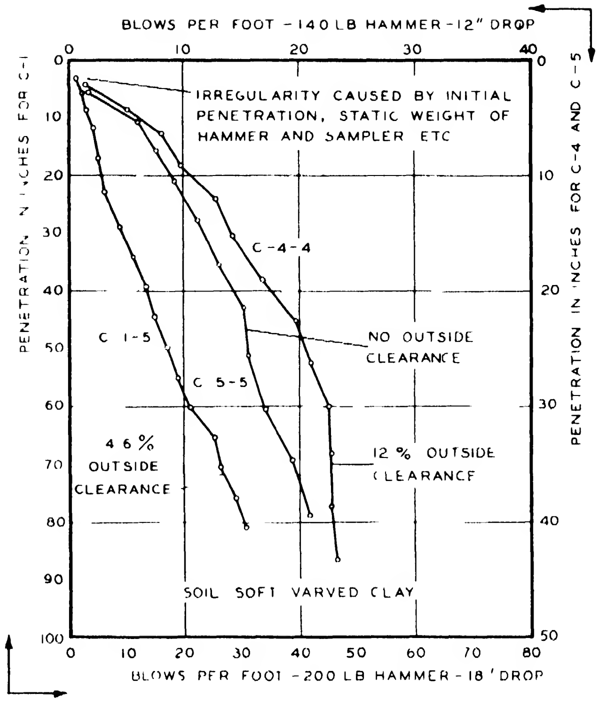
RECORDING SPRING
DYNAMOMETER
FIG 110

Complete dynamic and static penetration resistance diagrams were determined in many sampling experiments during the research. The driving diagrams obtained in the field were transformed into dynamic resistance diagrams as demonstrated in Fig. 111, and examples of such diagrams are shown in Fig. 107, 108, and 112. The diagram of static resistance in Fig. 113 was obtained with the recording spring dynamometer shown in Fig. 110. The general shape of both dynamic and static penetration resistance diagrams is illustrated in Fig. 114. After initial irregularities, the majority of the diagrams obtained have a fairly straight section, which by extrapolation indicates an initial resistance corresponding to the point resistance of the cutting edge, whereas the slope of the straight section primarily is governed by the inside and outside wall friction. The straight section extends approximately to the safe depth of penetration. When this depth is exceeded, the rate of increase



DRIVING AND RESISTANCE DIAGRAMS

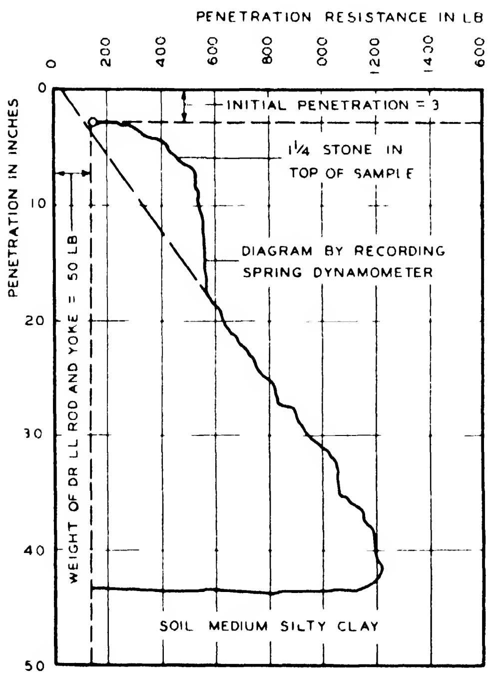
FIG 111



C 1-5 – MOHR SAMPLER O D = 5 50' I D = 4 72" – D_e – 4 58
C 4-4 – PORTER SAMPLER – O D 1 40 I D – 0 94' – D_e – 0 90
C-5-5 – SHELBY TUBING O D = 1 00 – I D – 0 94" – D_e – 0 93

PENETRATION RESISTANCE BY HAMMERING

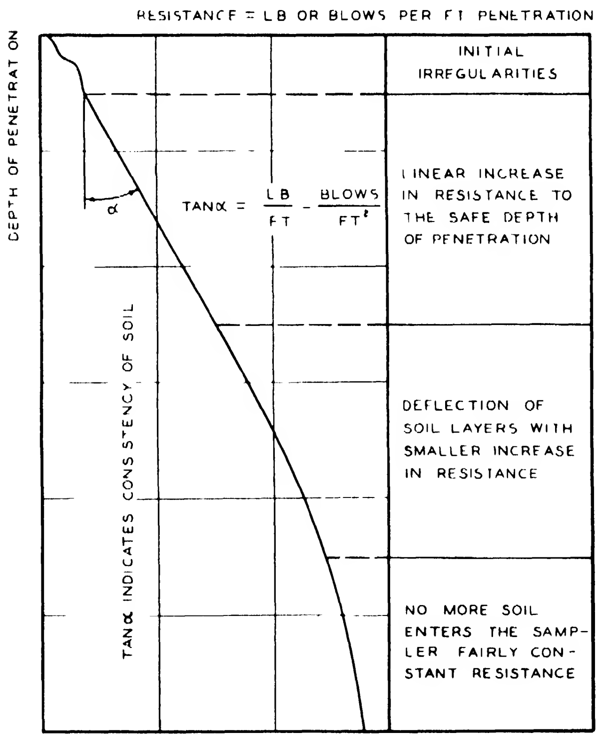
FIG 112



PISTON SAMPLER – O D = 2 00 I D = 1 93 C_i = 1 6 %
DEPTH = 44 5 TO 48 0 FT, RECOVERY = 97 5 %

PENETRATION RESISTANCE BY PUSHING

FIG 113



PENETRATION RESISTANCE OF A SAMPLER

FIG 114

of the penetration resistance decreases. Beyond the depth at which a permanent soil cone is formed below the sampler, and no more soil enters, the penetration resistance is governed by the outside wall friction and the point resistance of the sampler acting as a solid rod

It would appear that -- for a sampler without too heavy walls or excessive inside and outside clearances -- the penetration resistance and the corresponding density, consistency, or strength of the soil can be represented by a penetration resistance index equal to the tangent or tangents of the angles of inclination, α, of the straight sections of the penetration resistance diagram In uniform soil and in normal sampling operations, where the safe depth of penetration is not exceeded, it would suffice to determine the maximum penetration resistance -- in lb for static resistance and blows per foot penetration for dynamic resistance -- and to divide this resistance by the maximum depth of penetration in order to obtain an average penetration resistance index.

4.11 Open Drive Samplers

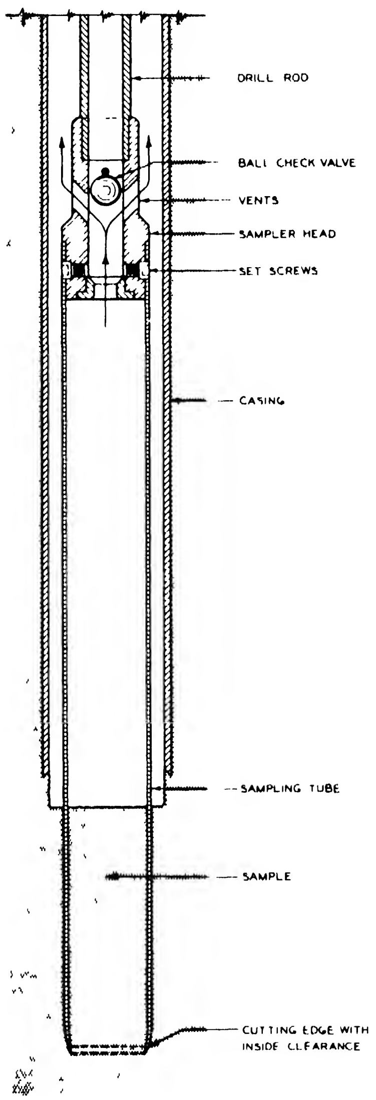
The first open drive samplers consisted simply of a section of standard pipe, beveled at the lower end and attached to the drill rod After the pipe sampler is withdrawn from the bore hole, the sample is pushed or shaken out, and a section of it is preserved in a sealed jar. The sample is seriously disturbed, and this type of sampler is only used in reconnaissance borings of small diameter

Thin-wall samplers.- A very simple drive sampler, suitable for obtaining undisturbed drive samples, was introduced in 1936 by **H. A. Mohr (339, 341).** It consists of a section of thin-walled "Shelby" or seamless steel or brass tubing, which is attached to a sampler head or adapter containing a check valve and vents for escape of air or water, Fig. 115. Later improvements consisted of providing the tubing with a sharp and drawn-in cutting edge The sample is normally preserved and shipped to the laboratory in the tubing, where it is cut into short sections so that the sample may be removed with a minimum of disturbance of the soil The waste of tubing can be avoided by pushing the sample out of the tubing in the field and preserving it in some other manner, but this method can be used only for relatively short samples, and even then there is danger of disturbing the sample by this operation

A thin-wall sampler may arbitrarily be defined as a sampling tube with a wall thickness less than 2.5 percent of the diameter, corresponding approximately to an area ratio of 10 percent when the inside clearance of the cutting edge is not taken into consideration The principal advantages of the thin-wall sampler are its simplicity and the small area ratio and consequent minimum of disturbance of the soil Its disadvantages are that the tubing is used only once and that it is easily damaged when used in hard or in dense and stony soils.

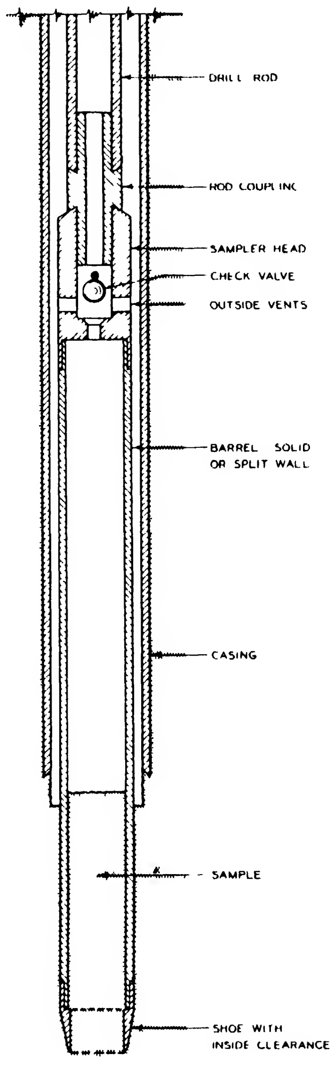
Thick-wall and composite samplers.- When a sampler is to be used repeatedly and in all types of soil, it is generally made of heavier tubing and is provided

with a detachable shoe and cutting edge of hardened steel, Fig. 116. When the sampler is short, the barrel may be split longitudinally in two parts, which are held together by the sampler head and the shoe but can be separated after the withdrawal, thereby facilitating removal of the sample However, the split barrel is primarily used when only a short section of the sample is to be preserved When the entire sample is to be shipped to the laboratory, the sampler generally has an inner tube



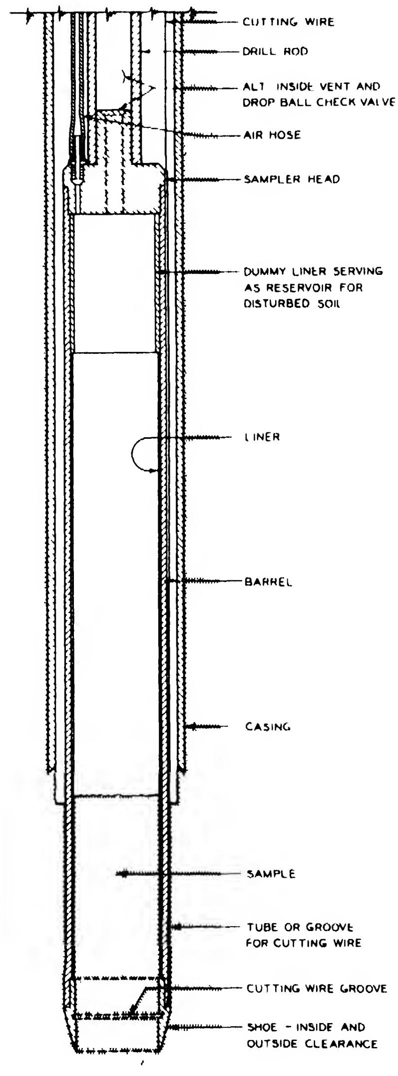
THIN-WALL OPEN DRIVE SAMPLER

FIG 115



THICK-WALL OPEN DRIVE SAMPLER

FIG 116



COMPOSITE OPEN DRIVE SAMPLER

FIG 117

or liner in which the sample is preserved, Fig 117. A short dummy liner or space in the sampler head should then be provided to serve as a reservoir for sludge and disturbed soil, which may be discarded or preserved separately.

The principal advantage of a composite sampler is that the liners and detachable shoe provide considerable flexibility in design and operation of the sampler

and facilitate handling of the sample in both the field and laboratory Furthermore, the liner sections can often be used again after removal of the sample, and waste of tubing is thereby avoided The disadvantage is that the over-all wall thickness is increased, and the area ratio of composite samplers of small diameter is generally too large when the sampler is to be used for obtaining undisturbed samples

Sampler head.- An open drive sampler is usually provided with outside vents and a check valve as shown in Fig 115 and 116, but an inside vent and a drop ball check valve are occasionally used, Fig 117, since the sampler then may be cleaned of sludge by pumping water through the drill rod before the ball is dropped and the actual sampling started The check valves are easily fouled and not always reliable, and they are ineffective in case of sampling in a dry bore hole Not only is it difficult to prevent leakage of air through the valve, but a slight downward movement of the sample will merely cause expansion of the air without a material decrease in the pressure over the sample, and once a downward movement has started, the entire sample may be lost Check valves are therefore in some cases supplemented or replaced with a hose connection to a vacuum pump so that a partial vacuum can be maintained over the sample, but as indicated in Section 4 6, an arbitrary and excessive decrease of the pressure over the sample may cause serious disturbance of samples of very soft soils and cohesionless soils

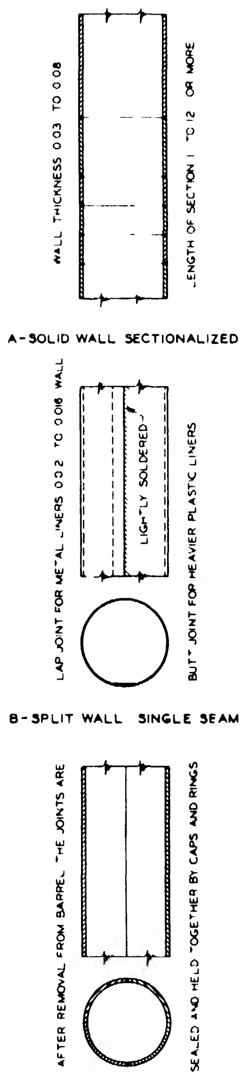
Tubing and liners.- The tubing for thin-walled samplers should preferably be hard-drawn, seamless steel tubing, although hard-drawn brass tubing may be used in soft soils The tubing should be clean and smooth to reduce wall friction A coating of hard and smooth lacquer is desirable, since it not only reduces wall friction but also prevents corrosion of the tubing and chemical changes of the soil during shipment and storage of the sample

Liners usually consist of thin-walled brass or galvanized steel or sheet metal tubing However, the galvanized coat is easily scratched by soil grains, and even brass tubing may corrode during protracted storage of the sample Liners of transparent plastic materials have been used in some cases; they have the advantages that they permit inspection of the surface of the sample, have a small coefficient of friction, and eliminate danger of corrosion However, they may absorb or transmit small amounts of water, they require a greater wall thickness than steel liners, and they are as yet difficult to obtain in the required dimensions. It is suggested that thin-walled steel or brass liners with a coating of a smooth, hard and tough lacquer be used

A continuous, seamless liner will cause a minimum of disturbance of the soil, but a long liner must later be cut into short sections to avoid disturbance of the soil during removal of the sample. Liners are therefore often divided into sections with a length of 3 to 6 times the diameter of the sample, Fig 118A, and even into very short sections equal to the required height of test specimens for consolidation and some types of shear tests. In the latter case, the samples can then be tested without removing them from the liner and without special preparation of test specimens.

Laboratory work is thereby facilitated and stress changes in the soil decreased However, liners divided into very short sections require a greater wall thickness than continuous liners, and there is always danger of some misalignment of the sections and consequent disturbance of the soil by protruding edges Leakage through the joints may cause loss of the lower part of the sample The field work is also increased by sealing of many individual liner sections, or the entire liner, divided into very short sections, must be placed in a special, sealed shipping container

The liner may also be split along one or two longitudinal seams, Fig 118B and C, which may be lightly soldered or sealed with tape Opening of the seams in the laboratory relieves the internal stresses in the sample and facilitates its removal from the liner, but it may also split the sample if the seam opens too much on account of residual stresses in the tubing Sealing of the seams with tape requires additional field work and is not reliable when samples are to be stored for protracted periods



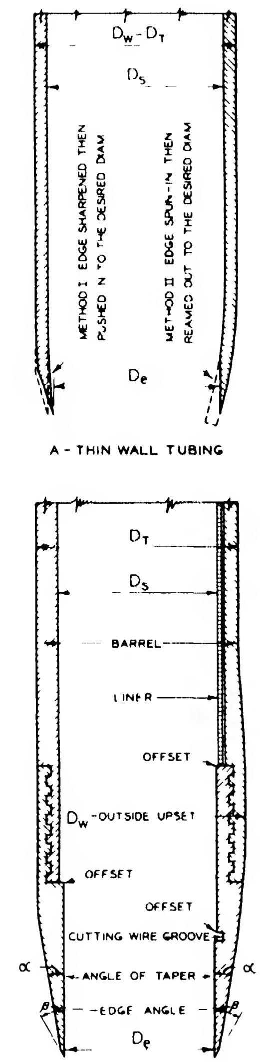
A-SOLID WALL SECTIONALIZED

B-SPLIT WALL SINGLE SEAM

C-SPLIT WALL DOUBLE SEAM

LINER TUBES

FIG 118



A - THIN WALL TUBING

B - SAMPLING TUBE SHOES

CUTTING EDGES

FIG 119

Shoes and cutting edges.- Two methods of preparing cutting edges on thin-wall tubing are shown in Fig 119A Method II is preferable since it provides a sturdier edge with a more definite diameter and inside clearance A detachable shoe and cutting edge is occasionally used, but a fully satisfactory method of fastening such a shoe to the thin-walled tubing without too great a loss in strength or an undesirable increase of the area ratio has not yet been developed

Examples of shoes for thick-wall and composite samplers are shown in Fig 119B. As indicated earlier, the entrance of excess soil on account of a large area ratio can be decreased by giving the shoe a very flat angle of taper, α in Fig 119B. In experiments with the M I T and Mohr samplers -- both having an inside diameter of 4-3/4 in. and an area ratio of approximately 44 percent -- it was found that in sampling close to the ground surface an angle of taper of 19° to 20° produced specific

recovery ratios of 125 percent, whereas 100 percent or no entrance of excess soil was obtained with an angle of 13° to 14°. However, at depths of 50 to 70 ft specific recovery ratios of 120 to 130 percent were obtained even when the angle of taper was reduced to 10° to 11° and the sampler was forced into the soil by fast pushing. The limiting value of the angle of taper for the cutting edge of a sampler with a large area ratio was not determined, and it can only be concluded that it should be less than 10°, or 20° when measured on the diameter. Close to the cutting edge it is, nevertheless, advisable to increase the angle to 20° or 30° -- β in Fig. 119B -- in order to avoid an easily damaged feather edge

Samples of small diameter can usually be separated from the subsoil by combined rotation and pulling, but this method often fails and causes loss of the sample when the diameter is large and the soil is tough As first suggested by **A. Casagrande,** such samples may be cut free by means of a wire loop, which is concealed in a groove in the shoe and pulled out before withdrawal of the sampler. The upper edge of the cutting wire groove should preferably be offset a little to avoid this edge engaging the soil and disturbing the sample. There should likewise be a small offset at the upper edge of the shoe where it joins the barrel of the liner, this offset should be larger than a possible misalignment of the liner combined with the commercial tolerance on its inside diameter.

Advantages and limitations.- The open drive sampler has the advantage of simplicity in construction and operation, but it also has several more or less serious disadvantages

(1) Mixed and disturbed soil at the bottom of the bore hole will enter and shavings from the sides of an uncased hole may enter the sampler. The upper part of the sample therefore often consists of non-representative or seriously disturbed soil

(2) The sampler will sink a little into the soil under the weight of the drill rod, especially when the soil is disturbed and soft; it is difficult to determine this initial penetration and therefore also the total penetration and total recovery ratio with sufficient accuracy.

(3) Unless the area ratio is small, excess soil may enter the sampler, in which case the upper part of the sample will be seriously disturbed, and the total recovery ratio will not furnish a reliable indication of the condition of the sample.

(4) When used in a bore hole filled with water or drilling fluid, an excess hydrostatic pressure will generally be produced over the sample during the drive and may cause soft soil to be pushed aside instead of entering the sampler.

(5) A check valve is not always effective in reducing the pressure over the sample during withdrawal of the sampler, and the samples are therefore often lost. Reduction of the pressure over the sample by means of a vacuum pump complicates the operation and may cause disturbance of samples of soft or cohesionless soils.

Satisfactory representative and undisturbed samples can be obtained with an open drive sampler, but a piston sampler is generally to be preferred when undisturbed samples are desired, especially when the soil is soft or when the bore hole is uncased.

4.12 Piston Samplers

A piston sampler is a drive sampler in which the lower end of the sampling tube is closed with a piston which can be released or withdrawn when the actual sampling is to be started

The great advantages of this type of sampler are that the piston prevents shavings from the walls of the bore hole and mixed and disturbed soil from the bottom of the hole from entering the sampler, and that the sampler can be used for advancing the boring by forcing the closed sampler into the undisturbed soil until the desired sampling depth is reached The time-consuming cleaning of the bore hole can thereby be decreased or, in some cases, entirely eliminated, and the extent of disturbance of the upper part of the sample is generally considerably smaller than for a sample obtained with an open drive sampler, see Fig. 73

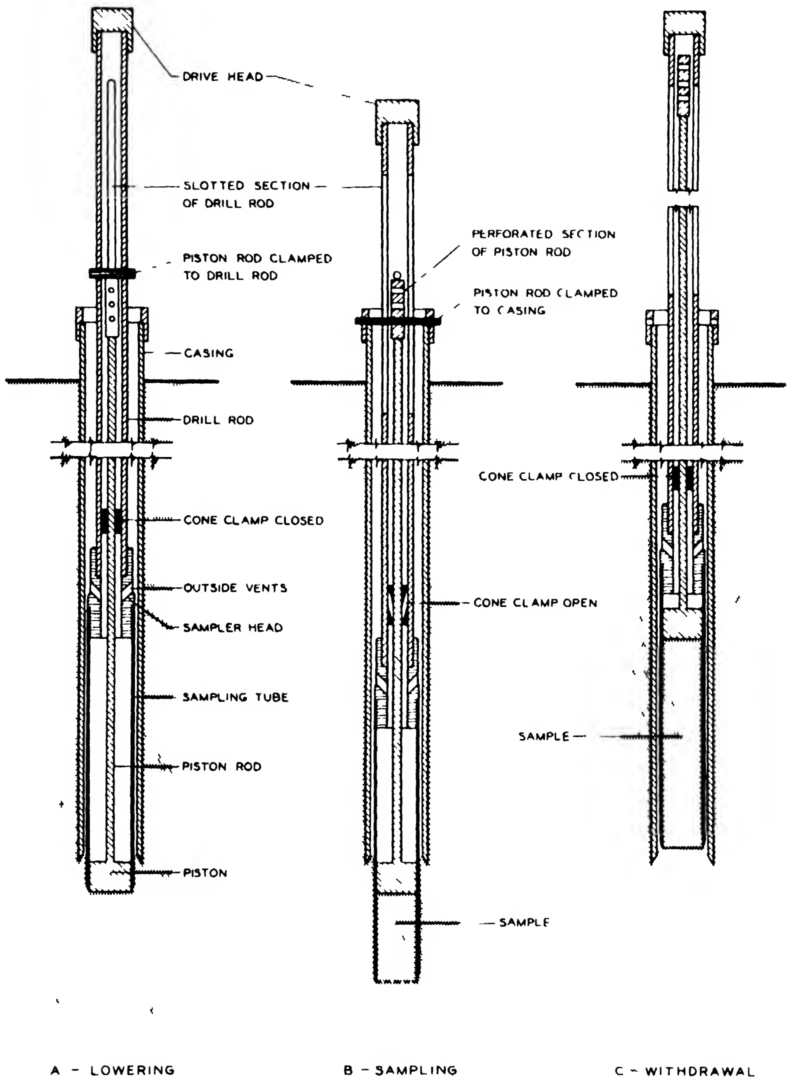
Piston samplers may be built as thin-wall or composite samplers, and the requirements and details of the tubing, liners, shoes, and cutting edges for open drive samplers apply also to piston samplers. The position and movements of the piston are controlled by means of a piston rod inside the drill rod, and the piston samplers may be classified in three types according to the manner in which the piston is operated during the actual sampling

Samplers with stationary piston.- The piston is held at constant elevation or stationary during the actual sampling The first sampler of this type was developed in 1925 by **John Olsson (539, 540).** The sampler shown diagrammatically in Fig 120 differs in some respects from the original Olsson sampler, and the clamping arrangements are only one of several types which have been developed The sampler is shown in a cased bore hole, but it can equally well be used in an uncased hole

The piston is flush with the cutting edge and the piston rod clamped to the drill rod while the sampler is lowered into the bore hole and forced through the soil to the desired sampling depth At this depth the clamp to the drill rod is released, and the piston rod is clamped to the casing or to a yoke at the ground surface, so that the piston will be held stationary while the sampler is forced around it into the soil. The surface clamp is released after the drive, but a cone clamp or other type of clamp automatically prevents a downward movement of the piston rod and piston during withdrawal of the sampler. The advantages of this method of operation may be summarized as follows·

(1) Entrance of excess soil is prevented and the influence of the area ratio

on disturbance of the soil is probably decreased, but this ratio should nevertheless be as small as possible



PISTON SAMPLER WITH STATIONARY PISTON

FIG 120

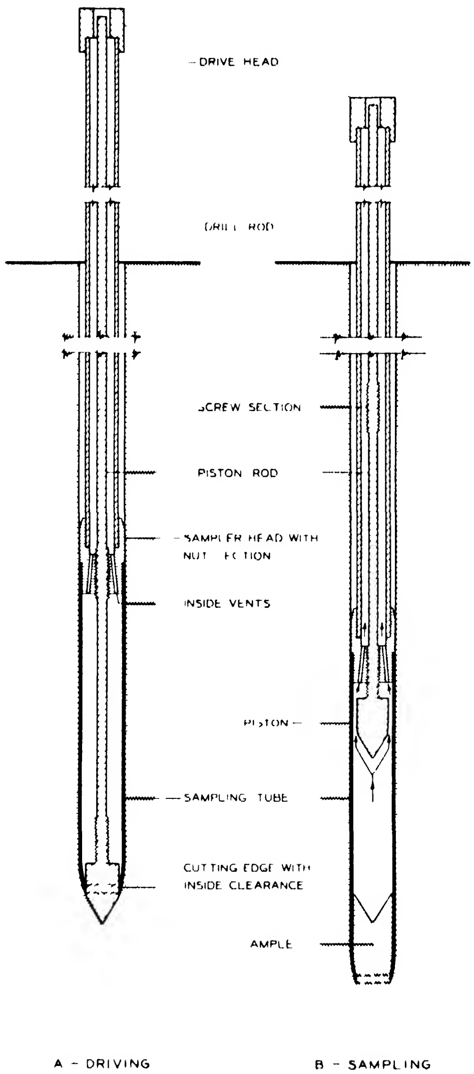
(2) Atmospheric and hydrostatic pressures over the piston are not transferred to the sample, and any tendency of the recovery ratio to fall below 100 percent is automatically counteracted by a decrease in pressure on top of the sample It thereby becomes possible to obtain longer samples, but in sampling of soft or cohesionless soil care should be taken not to exceed the safe depth of penetration, thereby creating a void between the piston and the top of the sample, since the ensuing upward flow of water may cause serious disturbance of samples of such soils.

(3) A piston with proper packing is tighter and less susceptible to fouling than a ball check valve, and the slightest downward movement of the sample during

the withdrawal will create a nearly full vacuum over the sample, thereby greatly decreasing the danger of losing the sample

(4) The penetration of the sampler and the gross length of the sample, and thereby also the total recovery ratio, can be determined easily and accurately Furthermore, since entrance of excess soil is prevented, a total recovery ratio of 100 percent indicates in this case that the specific recovery ratios also are close to 100 percent throughout the sample

The drive sampler with stationary piston is the best type of sampler, so far developed, for obtaining undisturbed samples through bore holes of fine-grained cohesionless soils and of soft to stiff cohesive soils In comparison with an open drive sampler, it has the disadvantage that its construction is somewhat more complicated and that the insertion, clamping, and withdrawal of the piston rod requires additional time However, this disadvantage is offset by a decrease in time required for advancing and cleaning the bore hole, by longer and better samples, and by a smaller percentage of lost samples



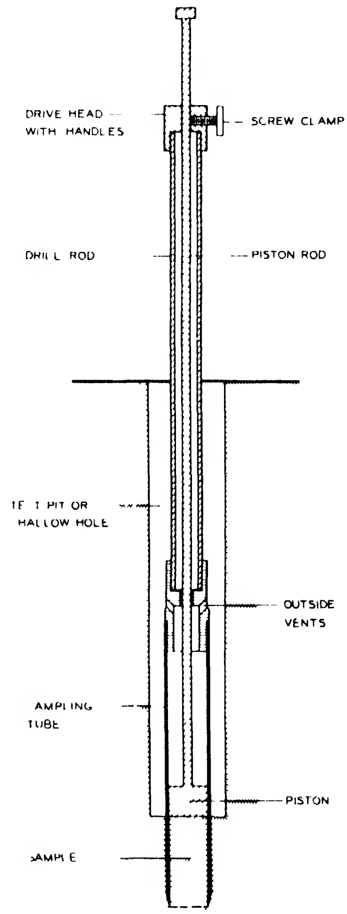
PISTON SAMPLER WITH RETRACTED PISTON

FIG 121

Samplers with retracted piston.- The piston is withdrawn to the top of the sampler just before the start of the actual sampling The sampler shown diagrammatically in Fig 121 is the California or Porter type (163, 347, 515, 550) The piston is held in its lower position by a nut section in the sampler head and threads on the lower part of the piston rod Upon reaching the desired sampling depth the piston rod is rotated and the piston thereby retracted until it is close to the nut section A small clearance between the piston and sampling tube or liner and inside vents in the nut section prevent formation of a vacuum during retraction of the piston and serve for escape of air or water during the actual sampling When the drive is completed, the piston is retracted further until it closes the vents in the sampler head

This sampler is simpler in both construction and operation than the sampler with a stationary piston, but several advantages of the latter are lost in obtaining these simplifications The retraction of the piston

may cause failure and a flow of soft soils into the sampler, and soil displaced by the walls of the sampler may enter as excess soil during the first part of the drive On the other hand, when there is sufficient leakage through the joints of the drill rod to fill the sampler with water, the top of the sample will be subject to excess hydrostatic pressures which may be greater than those in a corresponding open drive sampler, since it is difficult to provide large vent areas around the piston and in the nut section These consequences of retracting the piston may not seriously interfere with sampling of dense and stiff soils, but they increase the danger of disturbance of samples of loose or soft soils



SAMPLING POSITION

PISTON SAMPLER WITH FREE PISTON

FIG 122

Samplers with free piston - The piston is free to move with the top of the sample during the actual sampling operation The sampler shown in Fig 120 will act as a sampler with free piston when the piston rod is not clamped to the casing or ground surface during the drive A simpler design of a sampler of this type, for use near the ground surface, is shown in Fig 122 Operation of the sampler can be simplified and the pressure on top of the sample decreased by use of only a short section of piston rod and two clamps One of these clamps holds the piston flush with the cutting edge until the desired sampling depth is reached and is then released by rotation of the drill rod or by dropping an overshot through the rod, see Section 10 7 The other clamp is a cone clamp which prevents a downward movement of the piston during withdrawal of the sampler With such a clamping arrangement and a short piston rod, the operation of the sampler becomes simpler than that of other types of piston samplers and nearly as easy as that of an open drive sampler

The sampler with a free piston acts as an open drive sampler during the actual sampling, although the pressure on top of the sample is increased slightly by the weight of the piston and piston rod However, it is generally preferable to an open drive sampler since it prevents entrance of shavings and mixed soil, can be forced through undisturbed soil until the desired sampling depth is reached, permits easy and satisfactory determination of the total recovery ratio, and the piston is more effective than a check valve in reducing pressure over the sample during withdrawal This type of sampler is well suited for reconnaissance explorations and may also be used for obtaining undisturbed samples of stiff soils

4.13 Summary -- Design Criteria for Drive Samplers

The following summary of design requirements applies primarily to long samplers intended for use in not too coarse-grained, dense, or hard soils The use of steel foils to eliminate detrimental effects of the inside friction is discussed separately in Section 10 5 Compliance with the requirements does not guarantee that undisturbed samples will be obtained but should, at least, reduce disturbance of the samples

General Requirements

(1) **Diameter of sample.-** A diameter of 2 to 3 in. is usually satisfactory in detailed explorations and for samples intended for routine laboratory tests, whereas a diameter of 4 to 6 in is required when special tests or multiple tests on soil from a single stratum are to be performed

(2) **Length of sampler.-** Since the top and bottom sections of a sample often are partially disturbed, and since the danger of losing the sample during withdrawal decreases with its length, the sampler should preferably be long enough to utilize the safe depth of penetration, discussed on pages 107-109, although practical considerations in some cases may limit the maximum net length to about 5 ft

(3) **Wall thickness and area ratio.-** The area ratio should be reduced to the minimum compatible with the purpose and structural strength of the sampler and should preferably not exceed 10 to 15 percent, especially not for open drive samplers It is possible that the allowable limit is higher for samplers with a stationary piston, but simple thin-wall samplers will generally cause less disturbance of the soil than the heavier composite samplers

(4) **Shape of cutting edge.-** The cutting edge should be sharp and never rounded or blunt, and the angle of taper should be as small as practicable For a sampler with an area ratio exceeding 10 to 15 percent the angle of taper should be less than 10 degrees except close to the edge where the angle may be increased to 20 to 30 degrees in order to avoid an easily damaged feather edge.

(5) **Inside clearance.-** Except for very short samplers with no clearance, the inside clearance ratio should be from 0.5 to 3 0 percent according to the soil conditions. Larger ratios may be used under special conditions and when the primary object is to obtain long samples An inside clearance ratio of 0 75 to 1 5 percent is suggested for average conditions, but further experiments are desirable to determine the optimum values Commercial tolerances on the internal diameter of the tubing should be taken into consideration

(6) **Outside clearance.-** Samplers used in cohesionless soils should have no outside clearance, but a small outside clearance is desirable although not necessary for samplers used in cohesive soils Bearing in mind that the outside clearance increases the area ratio, it is tentatively suggested that the outside clearance ratio

should not exceed 2 to 3 percent, but its optimum range of values has not yet been determined.

(7) **Inside smoothness.-** The inside of the sampling tube or liner should be clean and smooth without any protruding edges or irregularities which may engage the soil. When grooves or core retainers are used, the upper edge of the groove should be offset slightly and the spaces between individual valves or leaves should be filled in so that a smooth and continuous interior surface is preserved.

(8) **Preservation of samples.-** The sampler should be so constructed that the sample can be preserved in the sampling tube itself or in a thin-walled liner. The tube or liner should be coated with a hard and smooth lacquer or consist of non-corrosive material, at least when the samples are to be stored in the tubing for an appreciable length of time. There is less danger of disturbance and loss of the sample when a continuous, in contrast to a sectionalized or split, liner is used

Open Drive Samplers

(9) **Reservoir for disturbed soil.-** Shavings and disturbed, excess soil in unknown quantities may enter an open sampler during its lowering into and seating on the bottom of the bore hole. The length of the tubing should therefore be longer than the nominal depth of penetration, or a suitable space or a dummy liner should be provided in the head of a composite sampler. A length of two to three times the diameter is suggested for this reservoir

(10) **Vents.-** Vents for escape of air or water over the sample should be large enough to prevent an objectionable increase in pressure over the sample The vent area of many currently used samplers is far too small When the sampler is used in bore holes filled with water or drilling fluid and is forced into the soil at high speed, as by a blow of a heavy hammer or by shooting, the vents should be streamlined and have an area equal to that of the sample.

(11) **Check valves.-** Check valves will help to prevent loss of the sample by reducing the pressure over the sample during the withdrawal, but they are not always reliable or fully effective. They should be so designed that they are not easily fouled and so that they provide the required vent area without materially increasing hydrostatic pressure by eddy losses.

(12) **Advantages and limitations.-** Open drive samplers are simple in construction and operation, but shavings and mixed soil and displaced, excess soil may enter the sampler. Excess pressures may be created over the sample, and it is often difficult to determine the recovery ratios with sufficient accuracy and to retain the sample during the withdrawal. The samplers may often be used to advantage in sampling of stiff and dense soils, but they are not well suited for obtaining undisturbed samples of loose or soft soils or for use in uncased bore holes

Piston Samplers

(13) **General advantages.-** Entrance of shavings and seriously disturbed soil at the bottom of the bore hole is prevented. The sampler can be used in both cased and uncased bore holes and for displacement boring The piston is more effective than a check valve in reducing pressure over the sample during withdrawal of the sampler and thereby in preventing loss of the sample.

(14) **Samplers with stationary piston.-** Entrance of displaced, excess soil during the actual sampling is prevented, and larger area ratios than in other samplers can probably be tolerated Pressure over the sample is decreased when the recovery ratio tends to fall below 100 percent, and longer samples can therefore be obtained, especially in soft soils. The total recovery ratio can be determined easily and accurately, and when this ratio is equal to 100 percent, it indicates for this type of sampler that the specific recovery ratios also are close to 100 percent throughout the sample The construction and operation are somewhat more complicated than for an open drive sampler and other types of piston samplers, but it is the best sampler, so far developed, for obtaining undisturbed samples of fine-grained, cohesionless soils and of soft, cohesive soils

(15) **Samplers with retracted piston.-** The sampler is simpler in construction and operation than a sampler with stationary piston, but retraction of the piston prior to actual sampling and the relatively small vent areas may cause disturbance of samples of soft soils The sampler may be used to advantage in reconnaissance exploration and in sampling of partially saturated soils and of stiff soils.

(16) **Samplers with free piston.-** The sampler acts as an open drive sampler during actual sampling and may cause disturbance of samples of soft soils, but it facilitates determination of recovery ratios and retains the general advantages of piston samplers It is simpler to operate than other piston samplers and may be used to advantage in reconnaissance exploration and in undisturbed sampling of stiff soils

4.14 The Normal Drive Sampling Operation

Even though the sampler is properly designed and the bore hole stabilized and carefully cleaned, short and disturbed samples may be obtained when improper methods are used to force the sampler into the soil, and the samples may be lost unless certain simple precautions are observed. The following directions apply to sampling operations in which difficulties normally are not encountered. Modifications and special methods and equipment to prevent loss of samples of soft or cohesionless soils are discussed in Section 4 15.

(1) **Preparations.-** The sampler should be carefully cleaned and vents, check valves or piston packing, clamps, and other parts checked for proper placement and functioning. Tubing or liners with the proper length and cutting edges or shoes with

the proper clearances for the soil conditions should be selected The lengths of the drill rods in made-up position should be checked since the cumulative effect of small deviations from the nominal length may be considerable for deep bore holes

(2) **Initial penetration.-** The penetration of an open sampler under its own weight and that of the drill rod should be determined as accurately as possible A piston sampler should be forced through the zone of soft and seriously disturbed soil before the piston is released and the actual sampling is started It is desirable also to determine the penetration of the closed sampler below the bottom of the bore hole

(3) **The actual sampling.-** Whenever possible, the sampler should be forced into the soil by fast, uninterrupted pushing A single blow of a heavy drop hammer or shooting will produce equally good results provided the sampler has sufficiently large and streamlined vents There must be no rotation of the sampler during the downward movement, and interruptions of this movement to re-set hydraulic cylinders, blocking, tackle, etc , will often cause a drop in the recovery ratio and increase the penetration resistance

(4) **Total penetration.-** The total penetration should not exceed the net length of the sampler, but it is advisable to utilize the safe depth of penetration as far as practicable This depth should not be exceeded when a sampler with stationary piston is used in soft or cohesionless soils, since a void then will be created over the sample and the ensuing upward flow of water may disturb the soil In other cases the total penetration may exceed the safe penetration for a distance of two to three times the diameter of the sampler, since the lower part of the sample generally will be partially disturbed anyway during withdrawal operations

(5) **Rest period.-** After completion of the drive, it is advisable to wait ten to twenty minutes before starting the actual separation and withdrawal operation in order to allow full development of adhesion and friction between the sample and the sampling tube

(6) **Separation of sample from subsoil.-** Before starting the actual withdrawal, a moderate pull should be exerted on the drill rod while it is rotated through two or three full revolutions to be certain that the rotation is transmitted to the sampler and not merely taken up in the joints of the drill rod The initial pull facilitates separation of the sample from the subsoil, but it should not be so great that it causes an upward movement of the drill rod before the sampler has been rotated

(7) **Withdrawal of the sampler.-** After rotation, the sampler should be withdrawn slowly and at uniform speed, great accelerations, shocks, and vibrations should be avoided, especially in sampling of soft or cohesionless soils The sample is occasionally lost at the moment the sampler is raised above the surface of water or drilling fluid in the bore hole This surface sinks as the drill rod and sampler are withdrawn, and it is advisable to keep the hole filled during withdrawal, unless the sampling is performed in a dry bore hole.

TABLE 7 - METHODS FOR PREVENTING LOSS OF SAMPLES

GROUP	METHOD	COMMENTS
REDUCTION OF PRESSURE OVER SAMPLE	Ball, disk, cock, or piston type check valve in sampler head	Ball check valve is not reliable All check valves are inefficient with air over sample
	Free or stationary piston with packing Piston closing vent by full retraction	Piston with good packing most efficient Do not overdrive sampler with stationary piston
	Rubber hose connecting sampler head with vacuum pump at ground surface	Arbitrary reduction of pressure may cause removal of fine particles piping, liquefaction
MINOR MODIFICATIONS	Increased length of the 'Rest Period' before start of withdrawal operations	Permits development of friction and adhesion Effective in some clays and silty soils
	Use cutting edge with increased diameter or decreased inside clearance	Do not fully eliminate inside clearance and cause excessive decrease in length of sample
	Replace sectionalized with continuous liner and seal joint to sampler head	Leakage through joints may cause part loss samples with strata or seams of porous soil
	Increase the depth or penetration if the safe depth" is not yet utilized	Often effective in cohesive soils Utilize safe depth of penetration whenever possible
	Use actual overdriving Release surface clamp of sampler with stat piston	Effective in cohesionless and partially saturated soils Causes distortion and compaction
CUTTING SAMPLE FREE	Thin steel wire placed in a groove in sampler shoe and pulled across sample	Often effective for samples of some tough cohesive soils and over 3 in in diameter
	Slightly curved steel springs pushed below sample making cone-shaped cut	Suitable only for short samplers Requires extra clearance and sliding drill rod joint
MAINTENANCE OF PRESSURE BELOW SAMPLER	External ribs or lugs forming annular clearance when sampler is rotated	Method simple but not reliable in saturated cohesionless soils or soft cohesive soils
	Injection of water or compressed air through conduits in wall of sampler	Often effective in cohesive soils Requires thick-wall sampler or exterior conduits
	Injection of water or compressed air through an auxiliary flattened pipe	Often effective used with thin-wall sampler Requires 1/2 in minimum clearance to casing
	Advance and concurrent cleaning of casing to sampler shoe before withdrawal	Often effective and prevents caving of hole Requires 1/2 in minimum clearance to casing
CORE RETAINERS	Exposed springs or fingers in sampler shoe also called basket type retainer	Springs structurally weak and cause increase in area ratio and direct disturbance of soil
	Concealed springs in sampler shoe, actuated by sliding liner or shoe	No direct disturbance, stronger springs can be used, but area ratio is greatly increased
	Multiple flap valves in sampler shoe, actuated by a wire and/or the sample	Increased wall thickness required and fillets between flaps to preserve interior smoothness
	Clamshell valves or cock valve in shoe actuated by wire or an external lever	Will retain very soft soils, silt, fine sand but require greatly increased wall thickness
	Core retainers in an auxiliary barrel pushed down along sampler after drive	For use with thin-wall samplers, but practical difficulties in construction and operat
SOLIDIFICATION OF SAMPLE BOTTOM	Injection through pipe to sampler shoe of chemicals forming an insoluble gel	Only for porous soils Extent of solidification uncertain, chemicals cannot be removed
	Advance, cleaning casing lower annular freezing unit, circulate cooled alcohol	For thin-wall samplers, 1-in min clearance to casing best method for fine sand or silt
SOLIDIFICATION OF SOIL BEFORE SAMPLING	Partial freezing or undercooling soil alcohol and dry ice in auxiliary pipes	Close control of cooling required Occasionally used in very loose, fine sand and silt
	Freezing by circulating cooling mixt through auxiliary pipes, core boring	Danger of soil expansion during freezing Undisturbed sampling of gravel in borings
	Impregnation with emulsified asphalt	Used only in porous soil Impregnation slow and removal of asphalt from sample difficult
	Casing capped, water replaced with compressed air before and during sampling	Method proposed for sampling of saturated loose sand and silt but not yet tried out

(8) Observations.- Detailed lists of required and desirable observations are given and discussed in Chapter 7 Here it shall only be emphasized that the initial and total penetration, the gross and net lengths of the sample, and the total recovery ratio should be determined very carefully, and they should be recorded even when the sampling operation is a partial or complete failure. These data give valuable information on the condition of the sample and serve as a constant guide for the drilling crew in estimating the proper depth of penetration and in selecting the proper type of sampler and method of sampling

4.15 Methods for Preventing Loss of Samples

As indicated in Section 4 6, to prevent loss of the sample during withdrawal (1) pressure over the sample should be decreased, (2) friction and adhesion between the sample and the sampling tube or liner should be allowed to develop to the maximum possible extent, (3) hydrostatic pressure below the sample should be maintained or increased, and (4) the sample must be separated from the subsoil Even when the sum of the downward forces is smaller than the sum of the upward or retaining forces, gradual loss of the sample may be caused by progressive internal failure of samples of very soft or cohesionless soils, especially when the diameter is large In general, the danger of loss of the sample increases with increasing diameter and decreases with increasing length of sample

A summary of the various methods used or proposed to prevent loss of samples is presented in Table 7 Special methods and appurtenant equipment are described in detail in Chapter 11 and only brief, general comments will be made in this section It should be noted that some of the methods require increased clearance between the sampler and the casing or walls of the bore hole In such cases the diameter of the casing or hole must be increased or a sampler of smaller diameter must be used, but a decrease of the diameter of the sampler may in itself be sufficient to prevent loss of the sample

Reduction of pressure over the sample.- In most drive samplers the pressure over the sample is reduced during withdrawal by means of a check valve or a piston with packing Ball check valves are easily fouled, and disk or piston type check valves are more reliable However, all check valves are inefficient when there is air over the sample, since a considerable downward movement of the sample then is required to produce an appreciable decrease in air pressure

Check valves have in some cases been supplemented or replaced with a rubber hose to a vacuum pump at the ground surface, and an upward flow of air or water through the sample is then maintained during withdrawal However, an arbitrary reduction of pressure over the sample and a strong upward flow of air or water may remove some of the fine-grained soil constituents and cause piping and even partial liquefaction of cohesionless soils. In general, it is better to use a sampler having a free or stationary piston with tight packing when the sample cannot be retained in an open

sampler with a check valve, but in sampling of very soft or cohesionless soils care should be taken not to overdrive a sampler with stationary piston, thereby creating a void over and a strong upward flow of water through the sample

Minor modifications in procedure and equipment.- Samples up to 2 or 3 in in diameter can usually be retained by use of normal sampling equipment and procedure or by minor modifications or adjustments of this procedure and equipment The objects of these modifications are to eliminate leakage, by sealing the joints of sectionalized liners or using continuous liners, and to increase the shearing strength of the soil and the friction and adhesion between the sample and the tubing The latter objects may be attained by increased length of the rest period between completion of the drive and the start of withdrawal operations, by a decrease of the inside clearance, and by an increase of the depth of penetration and length of sample

Actual overdriving or materially exceeding the safe depth of penetration is often effective in preventing loss of samples of cohesionless soils and fairly permeable or partially saturated soils, but it causes compaction of at least the lower part of the sample, and the method should not be used when undisturbed samples are to be obtained. When it is desired to overdrive a sampler with stationary piston, the surface clamp to the piston rod should be released after reaching the normal safe depth of penetration and before the actual overdriving is started Release of the piston rod will cause further entrance of soil to be resisted by the weight of the rod and piston, and it prevents formation of a vacuum over the sample with consequent upward flow of water through the sample, danger of partial liquefaction, and defeat of the purpose of overdriving

Cutting the sample free.- Attempts to separate the sample from the subsoil by twisting and a direct pull may cause loss of samples of certain clays, especially when the sample is relatively short or its diameter is greater than 3 in It may also be difficult to rotate the sampler before withdrawal when both the diameter and the depth of penetration are large

As indicated on page 127, the sample may be cut free by means of a thin steel wire which is placed in a groove in the sampler shoe and is pulled across the sample by means of a rope to the ground surface or by attaching it to a sliding drill rod joint Another method consists in forcing curved steel springs down along the outside of the sampler, Fig 245, or between the liner and sampler barrel A cone shaped cut is made when the sampler and springs are rotated, and the latter also provide some support of the sample. The method requires increased clearance between the sampler and casing or between the liner and sampler barrel and also a sliding drill rod joint or an auxiliary barrel for operation of the springs

Actual cutting of the sample, in comparison with separation by means of twisting and a direct pull, may reduce the extent of disturbance of the lower part of the sample.

Maintenance of pressure below the sampler.- Maintenance or increase of

hydrostatic pressure on the bottom of the sample is very effective in preventing loss of samples of cohesive soils but not always in sampling of saturated cohesionless soils.

Formation of a partial vacuum below the sampler during withdrawal may be prevented by providing the sampler with exterior ribs or lugs, **Harper (707)**, which form an annular clearance between the soil and the sampler when the latter is rotated However, such a clearance tends to close up in very soft soils and saturated cohesionless soils, and the method is therefore not always effective

Air or water may be admitted to the space below the bottom of the sample through conduits or channels in the sampler wall The required area of the conduits can be decreased when compressed air is used, **Mohr (341)**, and the pressure below the sample may even be increased until it forces the sampler out of the soil A specially constructed sampler is required, and the provision of conduits causes an increase in wall thickness and area ratio.

A method which can be used with thin-wall samplers consists in forcing a flattened pipe down along the sampler and injecting water or compressed air through the pipe, **Fahlquist (120)**. A clearance of at least 1/2 in between the sampler and the casing or wall of the bore hole is required to permit insertion of the flattened pipe.

The casing may also be advanced to the cutting edge of the sampler and the soil between the sampler and casing concurrently removed by jetting and washing through flattened pipes or an auxiliary barrel, Fig 232. This method has the advantage that it also decreases the danger of caving of the lower part of the bore hole

Core retainers.- One of the oldest and most widely used methods for preventing loss of samples of soil and rock consists in providing core springs, flap valves, or other types of core retainers in the sampler shoe The method is simple in operation and generally successful in retaining samples of stiff soils and rock, but it is not always effective when the sample consists of very soft soil or loose cohesionless soils, and the core retainer often causes disturbance of soil samples

Core retainers in samplers intended for undisturbed sampling of soils should be so designed that a smooth and continuous interior of the sampler is preserved when the core retainer is in open position, that is, there must be no protruding edges or unfilled recesses which can engage the soil as it enters the sampler Even when these conditions are fulfilled, core retainers are undesirable when placed in the sampler shoe, since they require increased wall thickness and area ratio of the sampler, and since a downward movement of the sample must take place in order to actuate the core retainer.

To avoid the undesirable features of core retainers in the sampler shoe, it has been proposed to place them in an auxiliary barrel which is pushed or jetted down around the sampler after completion of the drive However, there are certain practical difficulties in both design and operation of the auxiliary barrel, and the method has not yet been used in actual practice.

Solidification of the sample bottom.- The above mentioned methods may cause disturbance of and cannot always prevent loss of samples of cohesionless soil. Samples of these soils can be retained in the sampler by solidification of the lower part of the sample before withdrawal of the sampler

The solidification may be accomplished by injection of chemicals which later form an insoluble gel This method has been used only to a minor extent since it has several serious disadvantages When the chemicals are injected through conduits in the sampler walls leading to the shoe, the wall thickness and area ratio of the sampler become excessive. When the injection is made through auxiliary flattened pipes, pushed down along the sampler, the chemicals will also impregnate the soil below and around the cutting edge, and the solidified plug may be pulled out of the sampler and remain on the bottom of the hole The method can be used only in porous soils, and the chemicals cannot later be removed from the solidified part of the sample

Greater success has been attained by freezing the lower part of the sample, using a procedure developed by the Corps of Engineers, **Fahlquist (320, 520).** The casing is advanced to the cutting edge of the sampler and the soil between the sampler and casing removed by means of jetting and an annular auger A small annular freezing unit is then lowered to the bottom of the hole, and the lower part of the sample is frozen by circulating alcohol, cooled by dry ice, through the freezing unit At least 1-in. clearance is required between the sampler and casing for insertion of the freezing unit The method can be used with thin-wall samplers and irrespective of the permeability of the soil; it is the best method so far developed for undisturbed sampling of loose to medium-dense sand and silt through bore holes.

Solidification of the soil before sampling.- The soil may be partially or completely solidified before sampling Injection of chemicals which form an insoluble gel should not be used for this purpose, since the chemicals cannot be removed from the sample.

According to **Langer (150, 333),** partial solidification of loose and very uniform, fine sand and silt before sampling may be accomplished by means of a mixture of alcohol and dry ice in a series of pipes, driven into the ground and advanced a little ahead of the boring Care is taken not to freeze the soil but only to undercool it, whereby the viscosity is increased to such an extent that the danger of a change in void ratio is decreased and the samples can be retained in a drive sampler without core retainers

Complete freezing of the soil before sampling has been used successfully by the **Corps of Engineers (911).** The general procedure is essentially the same as described above, but cooled alcohol or brine is circulated until the soil inside the ring of pipes is completely frozen, whereupon samples are obtained by core boring. Freezing can be used in any type of soil and does not change the chemical composition of the sample. Water expands during freezing, but in fairly permeable soils of such gradation that ice lenses are not formed, it is possible that the expansion of water

during freezing simply will force some of the unfrozen water out of the soil and not change the void ratio or disturb the soil structure The method is expensive, but it is the only one so far developed by means of which relatively undisturbed samples of gravelly soils and of fissured and broken rock can be obtained through deep bore holes.

Solidification of the soil by impregnation with emulsified asphalt has been used in a few instances, but the method has several disadvantages It can be used only in porous soils and even then the impregnation and subsequent solidification may require considerable time Sampling of the impregnated soil by means of drive samplers is difficult, and removal of the asphalt from the sample is time-consuming and not always complete

A proposed but so far untried method of temporarily creating apparent cohesion in saturated, fine- to medium-grained, cohesionless soils consists in placing a cap on the casing and forcing the water out by maintaining excess air pressure in the casing A slight dewatering of the soil in the vicinity of the bottom of the hole will thereby take place, and this soil will then be acted upon by capillary forces which may prevent progressive failure and loss of the sample during withdrawal of the sampler

4.16 Core Barrels -- Types and Component Parts

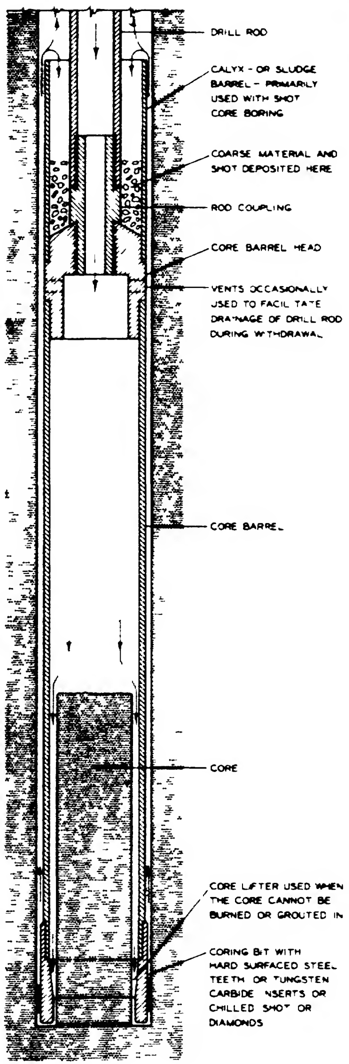
The samplers used in core boring are generally called core drills or core barrels, and the samples obtained are often called cores whether they consist of soil or rock

Whereas in drive sampling the material displaced by the walls or shoe of the sampling tube is pushed aside, in core boring this material is ground up and then removed by circulating water or drilling fluid. In a few special cases, when contact between the material to be sampled and a fluid must be avoided and the bore hole is kept dry, the cuttings are removed by circulating air or by means of narrow helical auger blades on the outside of the core barrel.

As in percussion and rotary drilling, the material may be ground up by either a chopping action or by rotation of the core barrel and its coring bit. Percussion core drilling is not used in soils and only to a minor extent in rock, and the following general review primarily concerns rotary core boring

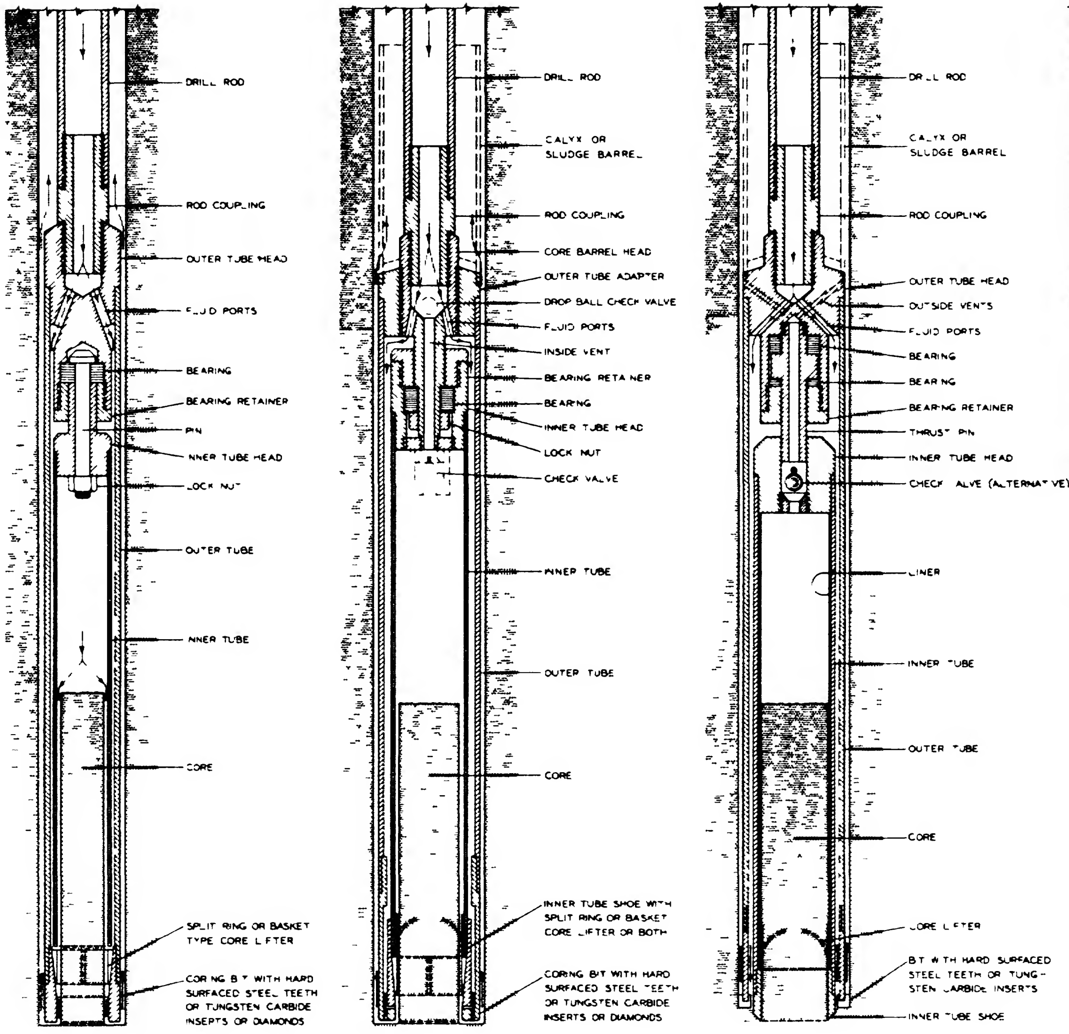
The principal types of rotary core barrels, commonly used in explorations for civil engineering purposes, are shown in Fig 123 and 124 However, there are several other types, and it should be noted that the component parts of the three double tube core barrels shown in Fig 124 often are interchanged and combined in various manners The percussion core barrel shown in Fig 125 will be discussed in Section 4 19.

Single tube core barrels.- The simplest type of rotary core barrel consists of a single tube with a coring bit, Fig. 123 The bit cuts an annular groove or kerf



SINGLE TUBE CORE BARREL

FIG 123



A

RETRACTED INNER BARREL

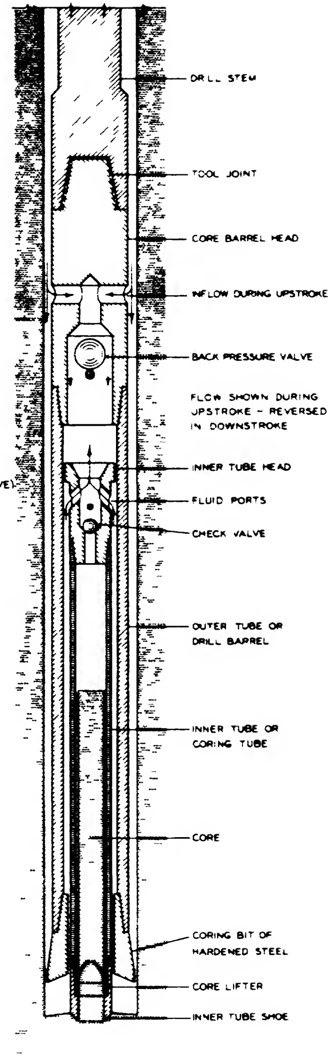
B

BOTTOM DISCHARGE

C

PROTRUDING INNER BARREL

FIG 124 - DOUBLE TUBE CORE BARRELS



PERCUSSION OR

CABLE TOOL CORE BARREL

FIG 125

with sufficient inside and outside clearance for passage of water or drilling fluid, pumped through the drill rod The core is exposed over its full length to contact with the circulating fluid, and the single tube core barrel is primarily used in materials which are not subject to erosion, slaking, or excessive swelling Occasionally the single tube core barrel is used in soils, in which case the cuttings are removed by circulating air or outside, helical auger blades, or the remolded material is simply forced up along the core barrel under its own pressure In the latter case the method is not true core boring but intermediate between core boring and drive sampling

Double tube core barrels.- To protect the core against action of the circulating fluid, double tube core barrels are commonly used in sampling of soils, of non-uniform, fissured, friable, and soft rock, and in general when the diameter of the core is small.

The inner tube may be rigidly connected to the core barrel head, in which case it rotates with the outer barrel and merely serves to protect the core against erosion and to keep the passages open. However, the swivel head types shown in Fig. 124 are generally preferred, since the inner tube then does not rotate during the actual coring, and the torsion transmitted to the core and attendant danger of breaking it are decreased Core barrels used in soils are generally also provided with a liner of thin-wall tubing, Fig 124C, in which the core is sealed and shipped to the laboratory.

Coring bits.- The actual grinding or cutting medium may be chilled shot, diamonds, tungsten-carbide inserts, steel teeth, or bladed or roller cutters. The shape of the bit and the type and arrangement of the cutting media vary with the type and diameter of the core barrel and with the character of the material to be sampled.

A simple straight or bevelled bit, Fig 123 and 124A, is used in single tube core barrels and in many double tube core barrels. In the latter the inner tube extends only to the top of the bit, and the lower part of the core is exposed to circulating water or drilling fluid This type of bit is primarily used in coring of fairly sound and uniform rock.

The bottom discharge bit, Fig. 124B, is used in soft and broken rock and often in soils The fluid passages are carried through the bit proper, and the inner tube has an extension or shoe with a core catcher unit reaching nearly to the edge of the coring bit. The core is then nearly, but not completely, protected against erosion and torsion. Further protection can be obtained by providing the inner tube with a shoe and sharp cutting edge which extends to or a little beyond the edge of the coring bit, Fig 124C, but this type can be used only in soils.

Core retainers.- Cores may be retained by grouting or "burning-in", as will be explained in the following section, but many single tube core barrels and nearly all double tube core barrels are provided with core retainers, also called core catchers or core lifters, which are placed in the coring bit or in the shoe of the inner tube. A tapered and fluted split ring, which grips the core after a short

downward movement, is generally used to retain cores of sound rock Core springs or a basket type core lifter or flap valves are used to retain cores of soft and broken rock and of soils

Vents and check valves.- Single tube core barrels are usually built without vents which would divert a part of the circulating fluid from the bit They are occasionally provided with small vents in the core barrel head or upper part of the barrel, Fig 123, in order to permit drainage of the drill rod, to prevent formation of excess hydrostatic pressures over the core during the withdrawal, and to avoid a "wet pull", that is, uncoupling of drill rods full of fluid which then splashes over equipment and drilling platform and interferes with efficient operation.

Many double tube core barrels of both rigid and swivel head types have no vents in the inner barrel, Fig 124A The fluid over the core must then be forced out between the core and the barrel as the core enters the tube Omission of vents prevents formation of excess hydrostatic pressures over the core during the withdrawal and without use of a check valve, but samples of soft and broken rock and of soils may expand and fill out the lower part of the inner tube before the coring is completed and thereby prevent or hinder escape of fluid over the core and further entrance of material Modern core barrels used in such materials are generally provided with vents and a check valve

The core barrel shown in Fig 124B has inside vents and may be provided with a fixed check valve, as shown below the inner tube head, or with a drop ball check valve The latter permits flushing of the core barrel by pumping fluid through the drill rod before the core barrel is seated on the bottom of the bore hole and the ball is dropped through the drill rod. Several other types of inside vents and check valves are used, but they all have the disadvantage that the hydrostatic pressure over the core is greater than that at the coring bit

Outside vents through the spindle to the low pressure area at the top of the outer barrel, Fig 124C, provide considerable reduction of hydrostatic pressure over the core and are preferable for core barrels used in soft rock and in soils. The outside vents may be combined with a fixed ball check valve, a disk valve, or a drop ball valve In the coring of soft and erodible materials care must be taken not to use too great a flow and pressure of the circulating fluid or allow the bit to ball up by improper feed pressure, since the fluid then may be forced up along the core and out through the outside vents and may cause erosion of the core On the other hand, such an upward flow of fluid along the core is purposely created in some core barrels to facilitate entrance of cores of solid rock, Fig 279.

Sludge barrel and calyx.- A flow of fluid able to carry the cuttings up through the large annular area between the drill rod and the casing or walls of the bore hole may cause excessive velocities around the bit and erosion of cores of soft materials. When an open-ended tube or sludge barrel is attached to the core barrel head, Fig. 123, the coarser cuttings will be deposited therein as the fluid flows into the low velocity area above the sludge barrel. The flow of fluid can then be decreased to

that required to remove the cuttings from the bit, the danger of erosion of the core is decreased, and it is easier to keep the bore hole clean.

A sludge barrel is also called a calyx on account of its resemblance to the calyx of a flower. It was first used with and forms an essential part of a shot core barrel, see Section 4.19. A calyx is often attached to large-diameter core barrels used in soft and broken rock or soils, but small-diameter core barrels for coring of hard rock are seldom provided with a calyx since the cuttings then are very small and high velocities of the circulating fluid are desirable to keep the bit cool

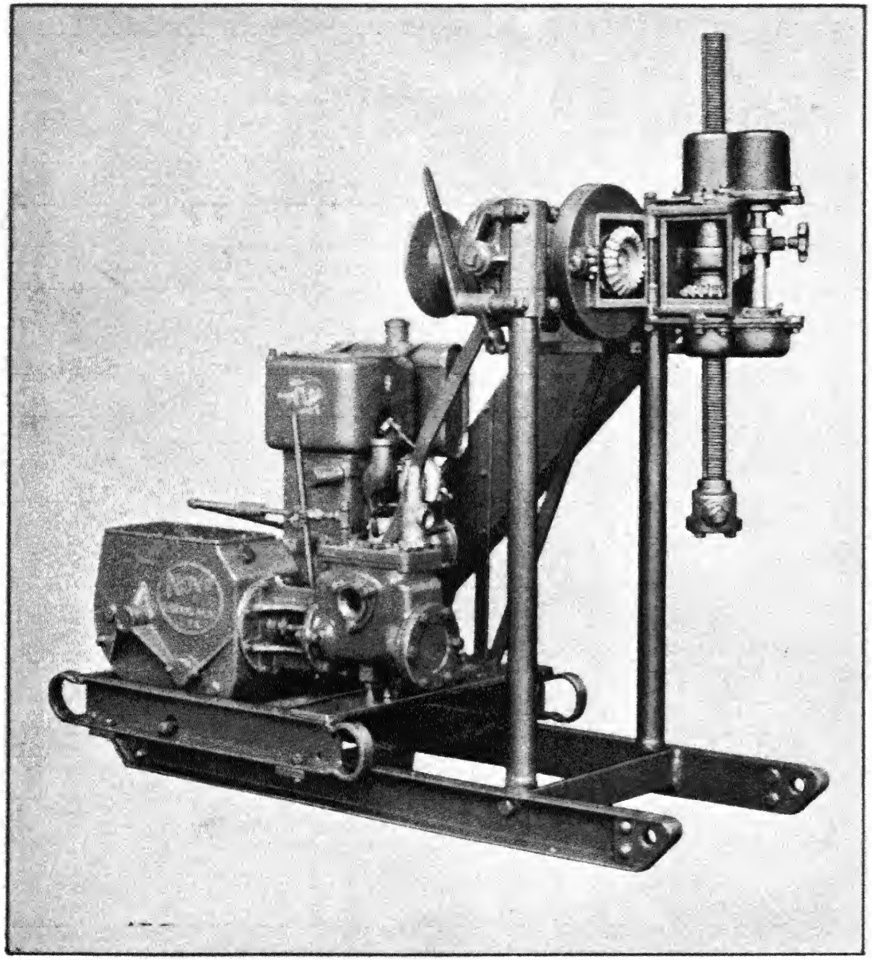
4.17 Drilling Machines and Operation of Core Barrels

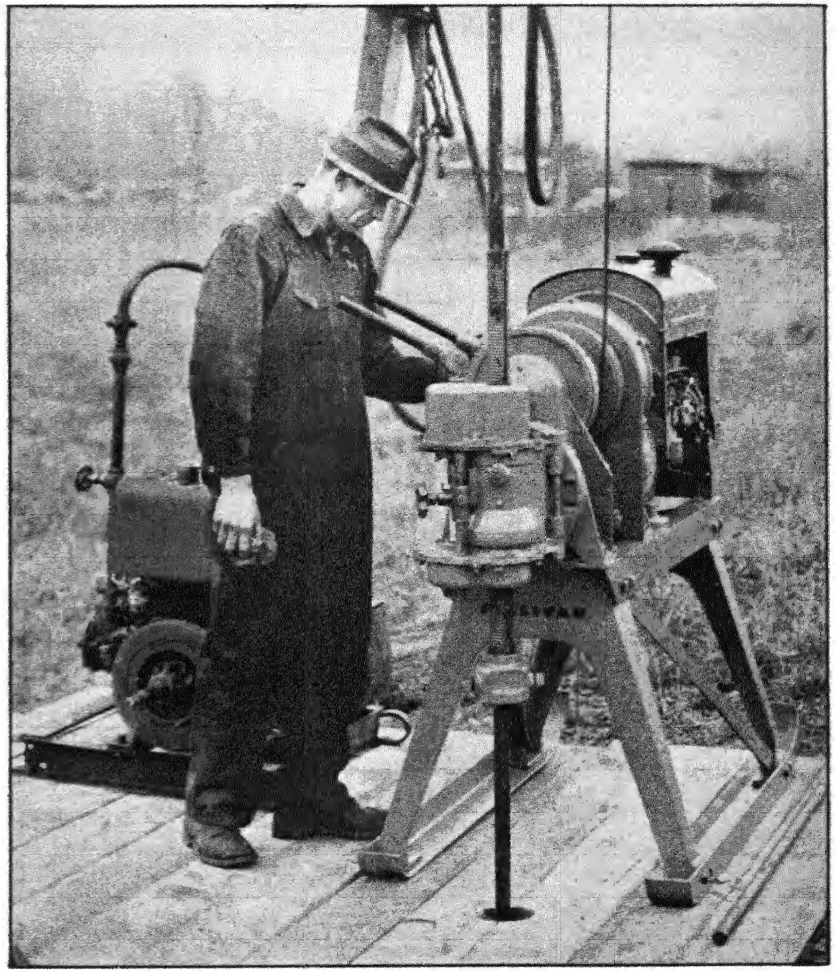
The operating equipment and procedure used in rotary core boring are similar to that for rotary drilling, and motorized drilling rigs of the type shown in Fig 37 and 38 are used both for straight drilling and core boring However, a large variety of drilling machines has been developed to meet the special requirements of various sizes and types of core barrels, bits, and cutting media. A few examples of such machines are shown in Fig 126 to 129

The drilling machines shown in Fig 126 are designed for small-diameter diamond core drills They have automatic screw feed and a swivel drill head which permits drilling in any direction. The drill head is also hinged and can be swung out for insertion or withdrawal of the drill rods and core barrel. The large machine shown in Fig 127 is primarily designed for diamond core drilling, but it can be used for straight exploratory boring and for operation of other types of core barrels and of drive samplers. It has twin hydraulic feed cylinders and a hinged drill head The latter is provided with two lugs for connection to earth anchors which are required when the downward thrust to be exerted on the drill rod is greater than the reaction corresponding to the weight of the machine Minor improvements have recently been made in the design of this machine, in particular the stroke of the hydraulic feed cylinders has been lengthened

Special drilling machines are generally used in operating shot core barrels, an example of such a machine is shown in Fig 128. The drill head is of the trunnion type, permitting inclinations up to 45°, and is mounted on a sliding base It has a hand-operated winch with pull-down ropes for exerting pressure on the drill rod and bit, but small machines of this type are provided with hand-operated screw or rack feed All the machines described above require a separate tripod or boring mast for handling drill rods

A very light and compact, all-purpose drilling unit with several novel features is shown in Fig 129. The drill head with its independent motor slides on a 6-ft long drill column, on which a single tubular mast with two sheaves is mounted A double drum hoist, a triplex pump, and a second motor are mounted on the skid frame The drill head has a hand-operated rack feed, and it can be swung aside after being moved to the top of the drill column.





A

SULLIVAN MACHINERY CO.

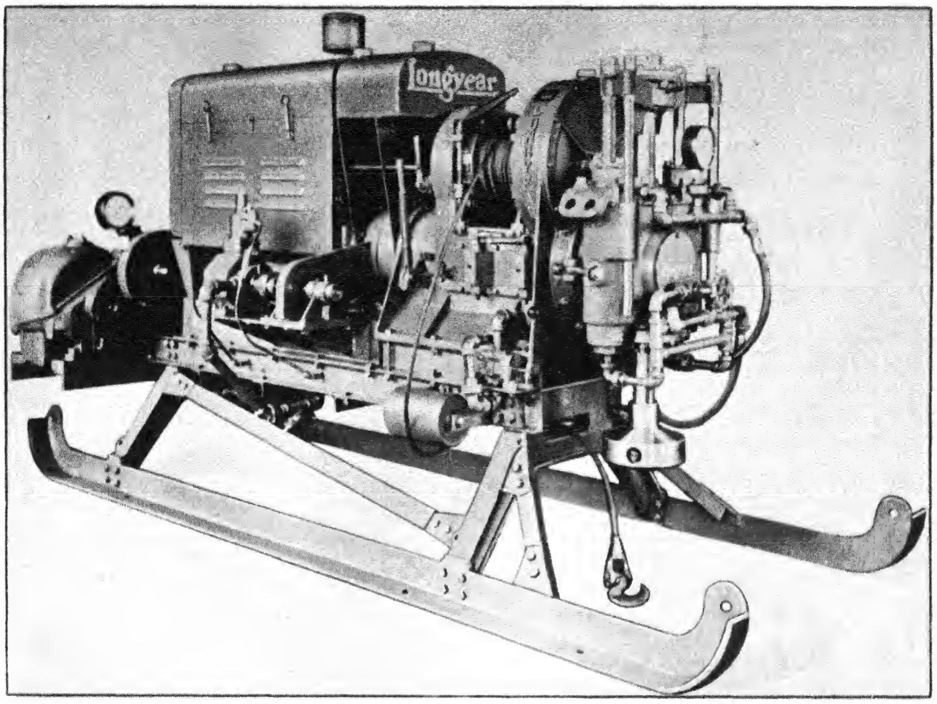
B

LIGHT UNIT WITH BUILT-IN PUMP, SWIVEL HEAD SWUNG OUT

MEDIUM SIZE UNIT WITH SEPARATE PUMP, IN DRILLING POSITION

CORE DRILLING MACHINES WITH SCREW FEED

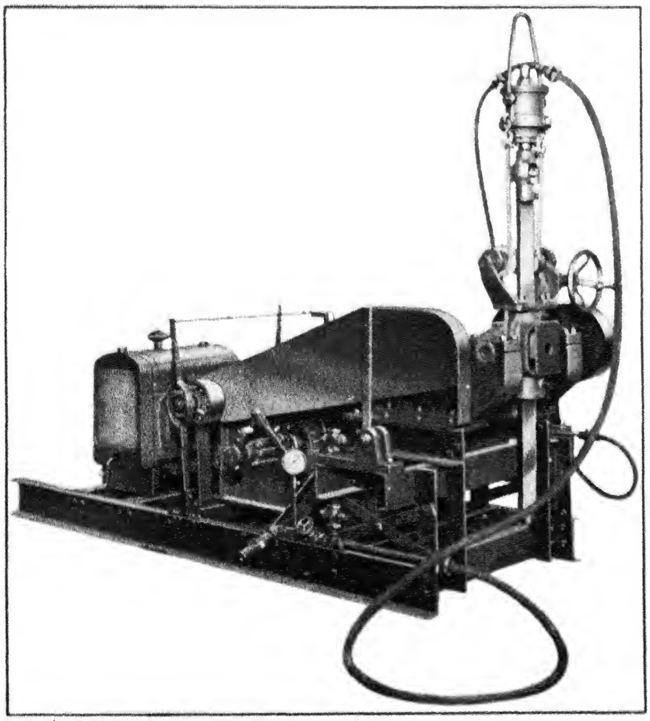
FIG. 126



E. J. LONGYEAR COMPANY

ATTACHED PUMP IN REAR, NOTE ANCHORING LUGS ON SWIVEL HEAD

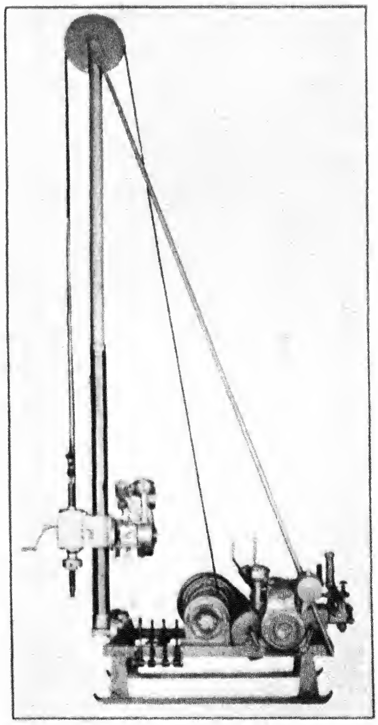
FIG. 127 - DRILLING MACHINE WITH HYDRAULIC FEED



INGERSOLL-RAND COMPANY

FEED AND PRESSURE REGULATED BY HOIST AND PULL-DOWN ROPES

FIG. 128-DRILLING MACHINE FOR SHOT CORE BORING



FRANK L. HOWARD ENG. CO., LOS ANGELES

HAND RACK FEED - SINGLE TUBULAR MAST

FIG. 129 - CONCORE EXPLORATION DRILL

Start of the bore hole.- In case of core boring in soil, the hole is usually started and advanced between samples by means of power augers or rotary drilling. A section of casing is used to prevent caving near the ground surface, but the remaining part of the hole is usually stabilized with drilling fluid For core boring in rock the casing is generally advanced to and sealed on rock, although stabilization and sealing of the walls of the hole with drilling fluid have been used to some extent in recent years. Clear water instead of drilling fluid is preferred for diamond and shot core boring in sound rock because the water is cheaper and adequate, requires smaller fluid passages, and does not cause the cuttings to be mixed with foreign material so that ''wet samples'' collected from the sump can be used for a rough identification and analysis of the subsurface formation

Cleaning of the bore hole.- A clean and full gage bore hole is required for obtaining long cores and good recovery ratios When there is a gradual squeezing-in of an uncased bore hole, it must be reamed out before the core barrel is inserted Large amounts of settled cuttings or disturbed soil at the bottom of the hole should be removed by straight drilling, by washing, or with bailers. In case of core boring in rock, it is standard practice to start the circulation of wash water before the core barrel reaches the bottom and to maintain this circulation for a short period before actual coring is started Small amounts of cuttings may thereby be removed and prevented from entering the barrel and clogging the fluid passages

In erodible soils the core barrel should be kept at a safe distance from the bottom during any final flushing of the bore hole, and the circulation of water or drilling fluid should be stopped or, at least, reduced to a very small amount while the core barrel is being lowered the remaining distance to and seated on the bottom. The circulation should be established before rotation of the barrel is started, and both the bit speed and rate of circulation should be increased slowly to their optimum values.

Speed of rotation.- The proper speed of rotation or bit speed varies greatly with the size and type of the core barrel and cutting medium and with the character of the material to be sampled Drilling machines are therefore capable, through gear shifts and throttling, of varying the bit speed within very wide limits The range of bit speeds in revolutions per minute is approximately as follows·

Bladed and roller cutters	25 to 80
Metal teeth, soils and soft rock	50 to 150
Shot core barrels	50 to 200
Metal teeth, medium hard rock	100 to 500
Diamond core barrels	300 to 1500

The average bit speed for modern, small diamond core barrels used in hard and uniform rock is about 1000 rpm, but speeds up to 1750 rpm are occasionally used.

To avoid whip and vibrations of the drill rod and core barrel, especially at high bit speeds, it is essential that the drill rod be carefully centered in the bore hole and chuck of the drill head, and that the drill rod in made-up condition is very

straight. A drill collar or section of drill rod with increased outside diameter, wall thickness, and weight is often inserted above large-diameter core barrels and tends to decrease whip and vibrations and the danger of breaking the core.

Too high a bit speed for a particular type of coring bit and subsurface formation causes whip and vibration of the core barrel, chattering and excessive wear of the bit, and breaking of the core A low bit speed decreases the rate of progress, but it will generally increase the recovery ratio and the length of core obtainable in a single operation, except when the rate of progress becomes so small that the material in the lower part of the core and below the bit is exposed to erosion by the circulating fluid for an excessively long period of time

Bit pressure and feed.- The pressure of the coring bit and its rate of advance or feed must be carefully adjusted in accordance with the character of the material encountered and the type of bit and bit speed Too high a pressure and rate of feed may damage the bit and will cause plugging of the bit and fluid passages and failure of the subsurface material before it enters the core barrel Too low a bit pressure and slow or intermittent feed may expose the core to excessive erosion and torsional stresses and may be equivalent to the "drilling-off" procedure used in separating the core from the formation

Control of the bit pressure and feed by means of a hand-operated screw or rack feed permits an **experienced** driller to detect small variations in the character of the subsurface material and to adjust accordingly not only the feed but also the bit speed and the pump pressure and discharge Hand operation is preferable when difficulties are encountered but it requires very experienced operators

Automatic screw feeds, Fig 126, are driven by the same shaft as the drill head, but the gear ratios can usually be changed in accordance with the general character of the formations encountered This type of feed gives satisfactory results in sound and uniform rock and is widely used for small-diameter diamond core barrels, since operation of the drilling machine then requires a minimum of attention and experience

Hydraulic feed by means of a single or, usually, twin hydraulic cylinders, Fig. 127, permits definite control of the bit pressure and, in some machines, also the rate of feed The bit pressure can be determined by a gage indicating the oil pressure in the hydraulic cylinders and is, for a given rate of feed and bit speed, indicative of the character of the formation being cored Hydraulic feed is more flexible in operation than automatic screw feed It can be used for any type of core barrel and in any material, and it is preferred for medium large core barrels and for coring of soils and of soft and non-uniform rock Some drilling machines are provided with chain or friction feeds which are equivalent in action to the hydraulic feed

The weight of large core barrels and long and heavy drill rods often exceeds the optimum bit pressure, and such barrels may then be suspended by the main cable and the bit pressure and feed regulated by means of the hoist. When the weight is

inadequate until a certain depth is attained, the bit pressure may be increased by a small hand-operated winch and pull-down ropes as shown in Fig. 128

Pump pressure and discharge.- In the majority of drilling machines the sludge pump is connected to the main drive shaft The pump speed for a given bit speed depends on the gear ratios used, but for a given gear ratio the pump speed varies directly with the bit speed Close control of the pump discharge is essential in coring of soft and erodible materials, in which case a pump driven by a separate motor is preferable, at least, a bypass and appropriate valves should be installed in the pump discharge line so that the actual rate of circulation of fluid can be controlled independently of the bit speed

Too small a rate of circulation of fluid causes the bit and fluid passages to be plugged, whereas too great a flow causes excessive erosion of both the core and the material below the bit and is one of the most frequent causes of failure of coring operations in weak and erodible materials In such formations the flow should be just sufficient to prevent the bit and fluid passages from clogging up, but a high pressure and a large flow are desirable in coring of hard rock and with high bit speeds in order to keep the bit cool and increase the rate of progress

Continuity of operation.- The coring should, as far as possible, be completed without interruptions which may cause clogging of the fluid passages and jamming or breaking of the core If the coring is stopped to add a section of drill rod or for other reasons, care should be taken not to lift the core barrel off the bottom, since the core retainer thereby may be activated Resumption of the coring may then cause jamming and damage of the core retainer, break off the core, prevent further entrance of material, or prevent re-activation of the core retainer during the actual withdrawal

Withdrawal operations.- Cores of sound rock and taken with small- and medium-size, single tube core barrels without core catchers may be retained by grouting, which consists in feeding uniform, small pea gravel with the wash water just before stopping the circulation and thereby packing the clearance between the core and the barrel with gravel This method is primarily used in shot core boring, see Section 4 19

Cores of soft rock and some soils, taken with single tube core barrels or double tube core barrels with a simple bit and retracted inner tube, can generally be retained by the "burning-in" or "dry blocking" procedure when the core barrel has no core catcher or the latter is ineffective This procedure consists in stopping the circulation of fluid and increasing the bit speed and feed for a short period, whereby the clearance between the barrel and the lower part of the core is packed with ground-up material. The method is not always effective for double tube, swivel type core barrels with bottom discharge, and it has the disadvantages that it causes serious disturbance of the lower part of the core, plugs the fluid passages, and prevents drainage of the drill rod. As a consequence, there is an excess hydrostatic pressure

over cores in single tube core barrels and double tube core barrels with inside vents, and the withdrawal operation is inconvenienced by a "wet pull"

When the core can be retained without "dry blocking", the withdrawal is started with "drilling-off", which consists in stopping the feed and increasing the bit speed and pump speed for a short period in an effort to separate the core from the formation The pump is generally kept running during the first part of the withdrawal in order to avoid a decrease of hydrostatic pressure below the core barrel The withdrawal should, in all cases, start rather slowly, and shocks and sudden changes in the speed of withdrawal should be avoided

Cores of sound rock and of large diameter cannot be broken loose and recovered by the above mentioned methods The core barrel is then withdrawn without the core and is replaced with another barrel having a core retainer and a special bit which undercuts the core, or with blasting caps attached to the lower edge of the barrel, Fig 276 Cores in accessible bore holes may also be broken free by means of wedges, whereupon a small hole is drilled in the center of the core, and a wedge pin or expansion eye bolt is inserted to permit hoisting the core to the surface A final "mucking-up" of broken and lost parts of the core is often required

4.18 Core Boring in Soil

Opportunities for detailed experiments on sampling of soils by means of core boring were not afforded during the research, and the following comments are tentative in character and mainly based on a few papers and reports on currently used equipment and methods and on such results of the experiments with drive samplers which also may be applicable to core boring in soil

Single tube core barrels and double tube core barrels with a retracted inner tube have been used to some extent in sampling of soils, and fairly representative samples have been obtained with these core barrels However, the samples are usually disturbed to a considerable degree by failure in torsion, swelling, and mixing or contamination with drilling fluid There can be little doubt that less disturbed samples of soils can be obtained by means of double tube core barrels with bottom discharge and an inner tube extending very close to or, in erodible soils, a little below the coring bit, Fig 124B and C

Forces during coring.- The soil below the core barrel is subject to a vertical compression corresponding to the feed pressure The distribution of this pressure between the area below the core and the annular area under the coring bit depends on the inside wall friction and the length of core To avoid disturbance of the soil directly below the core and entrance of excess soil, the feed pressure should be relatively small at the start of the coring, and it should be increased with increasing depth of penetration in order to maintain adequate pressure under the coring bit proper.

Rotation of the outer barrel and cutting of the annular groove subject the soil below the bit and in some cases also the lower part of the core to torsion The total torsion increases with increasing area of cut, or kerf area, whereas the ability of the core to withstand torsion increases with the cube of the diameter of the core The ratio between the kerf area and the cross-sectional area of the core corresponds to the area ratio of a drive sampler and should be reduced to the possible minimum, but it is not such a critical value for a core barrel as it is for a drive sampler On the other hand, the danger of disturbance of the sample increases much more rapidly with decreasing diameter of the core barrel than for a drive sampler

After the soil enters the inner tube, it is acted upon by approximately the same forces as in a drive sampler, and similar requirements apply in regard to interior smoothness, inside clearance, and reduction of pressure over the core The total recovery ratio will give some indication of the condition of the core, especially since the possibility of entrance of excess soil is relatively small On the other hand, a decrease in length of the core may be caused not only by compaction of the soil and downward deflection and stretching of soil layers but also by failure and erosion of weak strata

Design of core barrel.- In absence of systematic experiments in uniform soils, the following notes are mainly a summary of current practice supplemented by a few suggestions of possible improvements and new developments

(1) The core barrel should be of the double tube, swivel head type with bottom discharge and the inner tube extending to or a little below the coring bit A bottom discharge bit with a slightly retracted inner tube, Fig 124B, may be used in hard and impermeable soils

(2) Cores with a diameter of 4 to 6 in are taken with currently used core barrels, specially designed for use in soils The larger diameter is preferable when the soil has little or no cohesion, and it is questionable that fully satisfactory results of core boring in soil can be obtained with a core diameter of less than 4 in Depending upon the character of the soil, cores with a length of 2 to 5 ft are being obtained, but it is possible that considerably longer cores may be obtained with core barrels of improved design

(3) Although the kerf ratio or area ratio is not as critical as for a drive sampler, it should be reduced to the minimum possible without impairing the structural strength and stability of the core barrel, and without improper reduction of the area of fluid passages

(4) Several coring bits should be provided so that the teeth or cutters can be varied in number, shape, height, and outward projection or clearance in accordance with the character of the soil Currently used are hard surfaced steel teeth or tungsten carbide inserts The number of teeth varies from 4 to 12, their height from 1/8 in to 2 in, and the outward projection from 1/16 in to 1/2 in Systematic experiments to determine the optimum number, shape, and dimension of the teeth for various types of soils are needed, and consideration may be given to teeth with the cutting

edge or face under an angle with the radius, so that the teeth will tend to carry the cuttings toward the outer rim of the bit

(5) The inner tube should have interchangeable shoes so that the inside clearance and the projection below the outer barrel can be varied in accordance with the character of the soil The required inside clearance ratio is probably somewhat smaller than for a drive sampler, and a ratio of 0 5 to 1 0 percent is tentatively suggested The projection of the shoe below the coring bit varies in currently used core barrels from 0 to 3 in The cutting edge of the shoe should be sharp and have a flat taper, or the part projecting below the coring bit may be formed of thin-wall tubing

(6) The inner tube should be provided with a liner of thin-wall tubing to facilitate removal and proper preservation of the core Stove pipe or liners of 28 gage galvanized sheet metal are currently used as liners, but the inside friction can be decreased, and longer and less disturbed samples and better protection against corrosion can probably be obtained by use of thin-wall tubing with butt welded or no longitudinal joints and with a coating of a hard and smooth lacquer If the liner is divided into sections, the circumferential joints may be kept tight and in proper alignment by means of thin outside slip rings The inside diameter of the liner should be slightly larger than that of the top of the inner tube shoe in order to avoid a protruding edge, caused by a possible misalignment of the liner or by commercial tolerance on its inside diameter, that is, a part of the inside clearance should be provided at the joint between the shoe and the liner

(7) Although the inside wall friction may be sufficient to retain cores of some types of soils, a core retainer will be required to prevent loss of cores of other soils Basket or spring type core retainers are commonly used, they are simple in construction and operation, but they are also easily damaged, not fully reliable, and may disturb the core A valve or toggle type core retainer is preferable, provided a smooth and continuous interior surface of the shoe is maintained when the core retainer is in open position A fully satisfactory design of such a core retainer has not yet been developed A conical, split ring core retainer is not reliable for use in soils and soft rock unless it is combined with a spring type core retainer, see Fig 267 and 268

(8) The inner tube should be provided with adequate vents The required vent area is smaller than for a drive sampler, but considering that a rate of advance up to 3 ft per minute has been attained by core boring in some soils, it is suggested that the vent area should be 5 to 10 percent of the area of the core The efficiency of the vent may be increased by rounding the corners at the entrance Inside vents are used in some core barrels, but outside vents are preferable since they cause a considerable reduction of hydrostatic pressure over the core

(9) A check valve should be provided in the vent system in order to reduce the pressure over the core during the withdrawal The check valve should be so designed that it will not decrease the vent area or cause excessive eddy losses.

Ball type check valves are commonly used, but they are easily fouled, not always reliable, and are in some cases replaced with disk valves. Consideration may also be given to replacement of the check valve with a free piston -- with or without a short piston rod -- which is fastened to the inner tube shoe or clamped in such a manner that it is released when pressed against firm undisturbed material at the bottom of the hole or when the rotation is started. The piston should be provided with packing and an automatic clamp which permits upward but no downward movement of the piston Such a piston would prevent entrance of sludge into the inner tube, assure open position of the core retainer, and be more efficient than a check valve in reducing pressure over the core during the withdrawal

(10) A sludge barrel or calyx attached to the core barrel head will help to keep the bore hole clean and may reduce the required flow of drilling fluid and thereby decrease the danger of erosion of the core

The coring operation.- The operation of core barrels in both soil and rock has been discussed in Section 4 17 and only a few additional comments shall be made here

Clear water is occasionally used for core boring in soil, but drilling fluid is generally preferable since it permits use of a smaller flow and lower velocities and thereby decreases the danger of erosion of the core. There is some danger that cores of permeable soils may be contaminated by drilling fluid, but with core barrels having a bottom discharge bit and a flush or slightly protruding inner tube this contamination is usually confined to a zone extending only from 1 to 2 in. from the top and bottom of the core. The danger of contamination is increased when the soil is only partially saturated or nearly dry In such cases it has been attempted to replace the drilling fluid with compressed air, but fully satisfactory results have not yet been obtained

Vibrations and whip of the drill rod and core barrel are difficult to eliminate entirely and may cause disturbance of the sample. The tendency to vibration can be decreased by replacing the lower section or sections of the drill rod with a pipe of larger diameter and wall thickness, similar to the drill collar shown in Fig 37, or by use of larger and heavier drill rods throughout In core boring operations by the U S Bureau of Reclamation (518) the commonly used size "N" diamond core drill rods are replaced with 3-in. extra strong pipe

It is again emphasized that one of the most common causes of failure of core boring operations in soil is erosion of the material below the bit and in the lower part of the core. The pump discharge or actual rate of circulation of fluid should therefore be reduced to the minimum required to keep the bit and fluid passages clean Systematic experiments are needed to determine the optimum bit speeds, bit pressure and feed, and rate of circulation of fluid for various types of soils.

As mentioned, the total recovery ratio will give some indication of the condition of the core and should therefore be observed rather than the net recovery ratio.

A downward movement of the core to actuate a core retainer should be taken into consideration in computing the total recovery ratio The net length of the preserved core should be determined and noted in the boring record

Fields of application.- It is difficult if not impossible to force a drive sampler into hard and brittle clays, dense cohesionless soils, and partially cemented soils without causing partial failure and disturbance of the soil before it enters the sampler There is little doubt that less disturbed samples of such soils can be obtained by core boring This may even apply to such relatively soft and loose but highly brittle soils as loess, provided vibrations of the core barrel can be reduced to a negligible amount.

Undisturbed samples of soils containing considerable amounts of coarse gravel and stones cannot be obtained by drive sampling, they can be obtained by core boring but only when the soil is frozen before the coring

Water or drilling fluid may penetrate into cores of permeable and nearly dry soils and thereby render them unsuitable for laboratory tests Fully satisfactory methods for obtaining undisturbed samples of these soils by means of core boring, except close to the ground surface, have not yet been developed

Considerable difficulty has been experienced in retaining cores of saturated, loose and fine sand, and there is also danger that the void ratio of such soils may be changed during the coring since vibrations cannot be completely eliminated It is probable that less disturbed samples of loose and fine cohesionless soils can be obtained by means of thin-wall drive samplers

Core boring is not suited for sampling of soft and plastic cohesive soils, of which better samples can be obtained, and at less cost, by means of thin-wall drive samplers with stationary piston

4.19 Core Boring in Rock

Samples of rock are generally obtained by rotary core boring although percussion core boring still is used to some extent when the bore hole is advanced by percussion drilling Rotary core barrels used in rock are roughly classified in accordance with the cutting medium in the coring bit, that is, chilled shot, diamonds, steel teeth or hard metal inserts, and the bladed or roller cutters of hard surfaced steel used for oil field core barrels.

Forces during coring.- The rock below the core barrel and in the lower part of the core is subject to torsion and to vertical forces corresponding to the feed pressure The rock may fail under these forces and be broken up into fragments, but the deformations of unbroken sections of the core are generally negligible The core is cut with a slightly smaller diameter than the inside diameter of the core barrel or its inner tube and, excepting cores of certain soft and swelling rocks, there is very little inside wall friction as long as the core is unbroken However, the inside

friction is activated when the core is broken and rock fragments become wedged between the core and barrel or inner tube. A greater part of the feed pressure and in some cases also of the torsional forces may then be transmitted to the core and to the rock directly below the core The result is that weak sections of the rock and ultimately all the rock is broken up and removed by the circulating water or drilling fluid instead of entering the core barrel

Since the torsional moment of resistance of the core increases with the cube of its diameter, an increase in diameter is very effective in reducing breakage and increasing the recovery ratio and the length of core obtainable in a single operation A smooth and hard interior surface of the core barrel or the inner tube will also decrease the breakage and increase the recovery ratio, but an increase of the inside clearance has relatively little effect except in coring of swelling rock

Since the recovered sections of the core have not been subject to appreciable compaction or to reduction in thickness of the strata on account of downward deflection and stretching, the total recovery ratio does not give any indication of the condition of the recovered sections of the core but only of the maximum depth of penetration, or length of run, which can be used effectively In general, only the net recovery ratio is determined in case of core boring in rock The location and aggregate thickness but not the thickness of individual lost or ground-up sections can usually be determined by inspection of the recovered core Information on both the location and thickness of individual lost sections could be obtained from diagrams of specific recovery ratios, but such ratios are difficult to determine in case of core boring

Calyx or shot core boring.- Only single tube core barrels, Fig 123, are used The cutting medium is chilled steel shot, which is fed with the wash water and lodged around and partially embedded in a coring bit of soft steel To be effective the shot must be crushed during the coring, and pre-crushed shot, called Calyxite, is often used in coring of relatively soft rock The cuttings are removed from the bit by circulation of water and are deposited in the calyx above the barrel proper Shot core boring is therefore also known under the trade name Calyx Core Boring The flow of wash water must be carefully regulated so that it will remove the cuttings but not the chilled shot Cores of small diameter are retained by grouting, whereas cores of large diameter are recovered by means of a special core lifter barrel, wedge pins, or mucking after withdrawal of the core barrel proper

Shot core boring can be used in nearly all types of rock which are not subject to excessive erosion by the wash water, but it is most effective in medium hard and uniform rock The shot may become embedded in soft rock instead of grinding it up; in seamy or cavernous rock the shot is often lost, and the rate of progress is small in hard rock The method can be used only for downward boring and is best suited for vertical holes, but it can be used in holes with an angle of inclination up to 30 degrees Grinding by the rough shot subjects the core to considerable torsion, and although cores with a diameter of only 1-1/2 in. can be obtained under favorable

conditions, the method is primarily suited for taking large-diameter cores Cores up to 6 ft in diameter have been obtained by core boring, and it is the method most frequently used for securing large-diameter cores of and drilling accessible bore holes in rock during special explorations of sites for dams and similar structures

Diamond core boring.- The cutting medium is industrial diamonds, either carbons or bortz The former are the best, but the latter are most frequently used for coring bits, since cheap and reliable methods for mechanical setting of small diamonds have been developed during the last decade, see Section 13 5 Single tube core barrels are often used when the diameter of the core is large and the rock is sound and uniform, but double tube core barrels are preferable for taking cores of small diameter and when the rock is friable and non-uniform Clear wash water is generally used, especially when the cuttings are to be analyzed for mineral content, but drilling fluid may be required for stabilization of deep bore holes and when it is desired to avoid use of casing

Diamond core boring is primarily used in medium-hard to hard rock, and the diamond bit is often replaced with a bit having hard metal teeth or inserts when soft rock is encountered Smaller and smoother cores of hard rock can be obtained by diamond core boring than by other methods The smaller and most frequently used diamond core barrels are standardized in four sizes with the following designations and core diameters EX = 7/8 in , AX = 1-1/8 in., BX = 1-5/8 in , NX = 2-1/8 in Special diamond core barrels up to 8 in in diameter are occasionally used and still larger ones have been built, but diamond core boring is seldom used in foundation explorations when the diameter of the core is more than 3 to 4 in

Faster progress in hard rock can be obtained with diamond core boring than with other methods, and the small diameter of the core barrels and consequent relatively light weight of the drilling machines and equipment make diamond core boring well suited for reconnaissance explorations in rock It is the method most frequently used when foundation explorations are to be extended into firm rock

Core barrels with metal teeth.- The coring bit is provided with teeth or cutters which may be formed by machining or forging but usually consist of inserts which can be replaced when worn The inserts may consist of hard surfaced steel or entirely of very hard and abrasive resistant tungsten carbide alloys which are sold under various trade names such as Haystellite, Borium, Carboloy, etc

Single tube core barrels with metal teeth are used for taking large-diameter cores in soft, seamy, or cavernous rock where shot core boring is inefficient or cannot be used Double tube core barrels with hard metal inserts in the coring bits are used for taking cores from 2 to 8 in in diameter of soft to medium-hard rock Coring bits with hard metal inserts are less expensive than corresponding diamond bits, but the rate of progress in hard rock is much smaller than with diamond bits The hard metal coring bits also wear too rapidly in hard rock, causing the diameter of the bore hole to be decreased so that a core barrel with a new or redressed bit

cannot be inserted before the bore hole has been reamed out to full gage

Oil field core barrels.- Special core barrels have been developed for use with rotary drilling of very deep bore holes in search for oil The coring bits are similar to the rotary drilling bits shown in Fig 43 and 44 Bladed or drag bits are used in soft formations and various types of cone or roller bits in the harder formations

The core barrels embody many special features and may be classified in two principal types, the regular and the wire line core barrels The regular core barrels are essentially double tube core barrels with a floating inner tube and bottom discharge Some of these barrels have inside vents and a drop ball check valve, others have outside vents, and in one type of barrel the inner tube is provided with a sectionalized telescoping liner The core diameters vary from 1-1/4 in to 5-1/2 in, and the corresponding minimum O D of bit or diameter of bore hole varies from 3-7/8 in to 12 in

The wire line core barrels have an inner tube which can be inserted by dropping it through the drill rod and withdrawn by means of an overshot attached to a wire line, see Fig 291 The time consuming withdrawal of drill rods each time a core is taken is thereby eliminated and the rate of progress greatly increased when the bore hole is deep The diameter of the retractable inner tube is governed by the inside diameter of the drill rod The core diameters vary from 1 in to 2-1/2 in and the corresponding minimum hole diameters from 5-3/8 in to 8 in

Core barrels with an inner tube which can be sealed by means of a cock valve before the withdrawal, so that the hydrostatic pressure in and around the core can be maintained, have been built but are still in process of development

Several features first developed for oil field core barrels have been incorporated in core barrels used in foundation exploration, and other features may be used to advantage However, the diameters of cores obtained with commercially available oil field core barrels are small compared to the corresponding diameters of the core hole, and the barrels are also much heavier than those normally used in the relatively shallow borings for foundation explorations Nevertheless, the regular oil field core barrels are occasionally used for the latter purpose in regions where the required equipment is readily available

Percussion or cable tool core barrels.- As percussion or cable tool drilling was the first successful method for drilling deep bore holes through rock, so is the percussion or cable tool core barrel the first tool developed for obtaining cores of rock through deep bore holes

The percussion core barrel, Fig 125, is attached to the drill stem or jar of a string of cable tools, Fig 30 The core barrel consists of an outer barrel with a hardened steel bit and an inner barrel with a vent, check valve, and core retainer The inner barrel remains in contact with the rock and slides down over the core as the surrounding material is cut away by raising and dropping the outer barrel Water

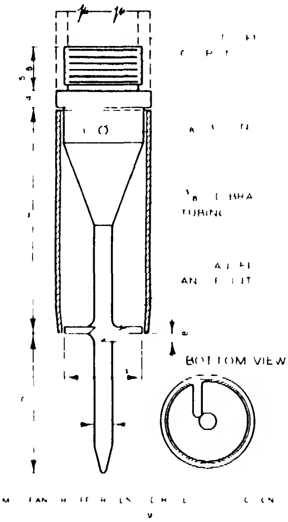
flows into the head of the outer barrel on each upstroke and is expelled through the bit on the downstroke, thereby causing temporary removal of the sludge below the bit Cores from 1 6 in to 3 8 in in diameter are obtained with bits having outside diameters from 3 7 in to 7 in.

The cable tool core barrel can be used in materials ranging from dense and partially cemented soils to medium-hard rock The cores are usually partially disturbed and the rock broken into short sections, but good over-all recovery ratios can be obtained under favorable conditions.

4.20 Surface and Control Sampling

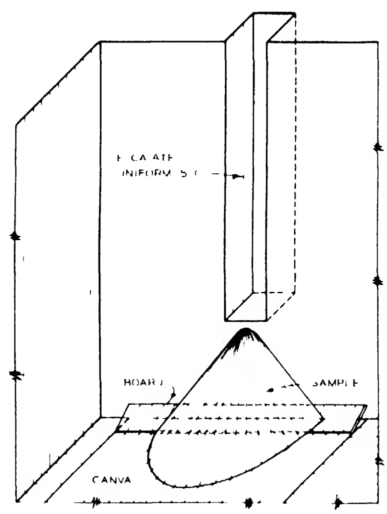
The following review covers control sampling during the construction of earth structures and sampling through very shallow bore holes or close to the soil surface in open excavations, test pits, and other accessible explorations To avoid disturbance of the soil to be sampled, the precautions outlined in Section 2 18 should be observed

Representative samples.- Disturbed but representative samples may be obtained by careful excavation or, in shallow bore holes, by means of short augers of the types shown in Fig 47 to 53 and 130 Composite representative samples are obtained by preserving all the material excavated between appropriate elevations in a bore hole or from a narrow channel in the walls of an open excavation or test pit, Fig 131 When the composite sample is too large, it may be reduced by quartering after thorough mixing The samples are preserved in jars, cans, boxes, or tightly woven canvas bags



SLEEVE AUGER

FIG 130

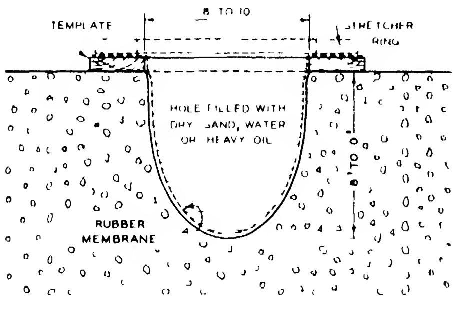


COMPOSITE REPRESENTATIVE SAMPLE

FIG 131

Field volume determinations.- The principal object of many foundation explorations and most control sampling operations is to determine the unit weight, water content, and void ratio of the soil in situ Representative samples are satisfactory for such purposes provided the original volume of all the soil in the sample is determined in the field This volume may be determined by careful excavation from a plane and level surface, Fig 132, and measuring the quantity of water, heavy

oil, or dry sand of known unit weight required to fill the excavated hole When water is used for this purpose, the hole must first be lined with a thin rubber sheet, but heavy oil may be used without such a lining unless the soil is very porous. The method is widely used for sampling and unit weight determinations of very coarse-grained and gravelly soils



FIELD VOLUME DETERMINATION
FIG 132

Residual stresses in the soil tend to decrease the diameter of the excavated hole and may thereby cause the unit weight determined to be slightly larger than the unit weight of the soil in situ The method may therefore be used as a complementary or control method to the advance trimming and block sampling methods which tend to furnish too low values of the unit weight

Drive sampling.- The open drive samplers and piston samplers used in bore holes may also be used for surface drive sampling, but simple, short samplers of thin-wall tubing are generally preferred, especially in control sampling and when the principal object is to obtain samples for determination of the unit weight of the soil

The sampling tubes used for this purpose have a diameter of 1 to 6 in and corresponding lengths of 2 to 6 in A diameter of 2 in is generally satisfactory for sampling and unit weight determinations of soft to stiff cohesive soils, silt, and fine sand, but a diameter of 3 to 4 in should be used in strongly compacted and coarser grained soils The sampling tubes should have a sharp cutting edge but are generally without inside and outside clearance, although a small inside clearance may be advantageous in sampling of some very dense soils

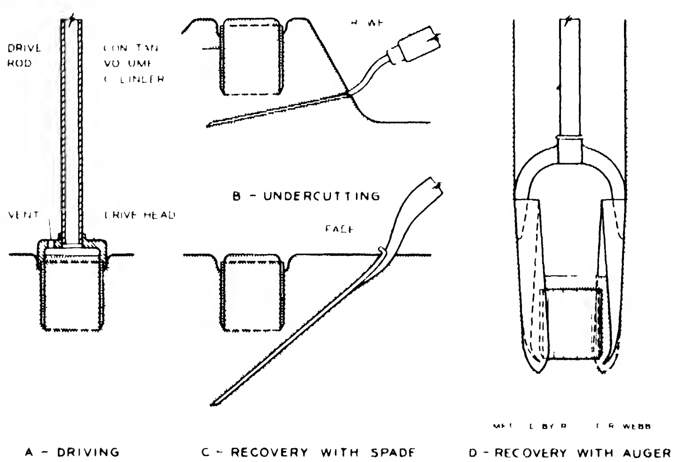


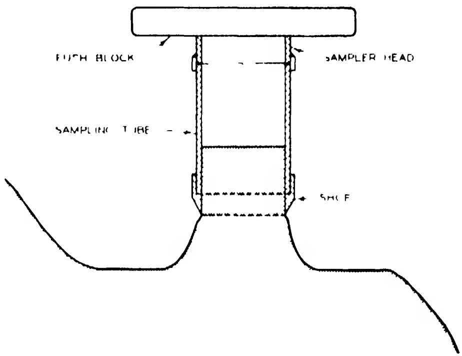
FIG 133 - CONSTANT VOLUME DRIVE SAMPLER

The sampler should, as far as possible, be pushed into the soil in a fast and uniform movement without wiggling The sample is generally cut free from the subsoil by undercutting and inserting a trowel or spade under the sampler, Fig 133B and C In case of sampling through shallow bore holes, the sampler may be recovered by means of a post-hole auger with the blades forced sufficiently apart to permit entrance of the tube, Fig 133D. Short piston samplers can be used to advantage, since the piston tends to prevent loss of the sample and thereby often permits withdrawal of the sampler without

undercutting or use of a spade or auger, see Section 15.4. Samples taken with short, open drive samplers are generally preserved in the sampling tube, and the unit weight is readily determined when the tubes have constant diameter and length.

Drive sampling is primarily suited for sampling of soft to stiff cohesive soils, silt, and loose to medium-dense fine sand. It cannot be used in gravelly soils, and the advance trimming and block sampling methods are preferable in very stiff and dense soils. However, the method is fast and convenient and widely used in control sampling of strongly compacted soils, in which it may be necessary to force the sampler into the soil by mechanical jacks or by hammering. There is danger of compaction of the sample when great force is required to push or drive the sampler into the soil. When the method nevertheless is used for control sampling of strongly compacted soils, it is advisable to determine the range of possible errors and necessary corrections by comparing the unit weights of some of the samples with the results obtained by other methods of sampling.

Advance trimming.- The disturbance caused by displacement of soil during drive sampling can to a large extent be eliminated by trimming the sample roughly to size a little in advance of the cutting edge while the sampler is pushed down carefully over the soil column, Fig. 134. Advance trimming makes it possible to use tubes with a relatively large wall thickness and thereby sampling tubes of transparent plastics, which have the advantage that voids caused by improper and excess advance trimming can be detected. The samples are generally preserved in the tube except when the principal object is to determine the unit weight of the soil. Short samplers of constant volume are then used and are trimmed and weighed after withdrawal, whereupon the samples may be removed and, if required, preserved in a bag or convenient container.



SAMPLING BY ADVANCE TRIMMING

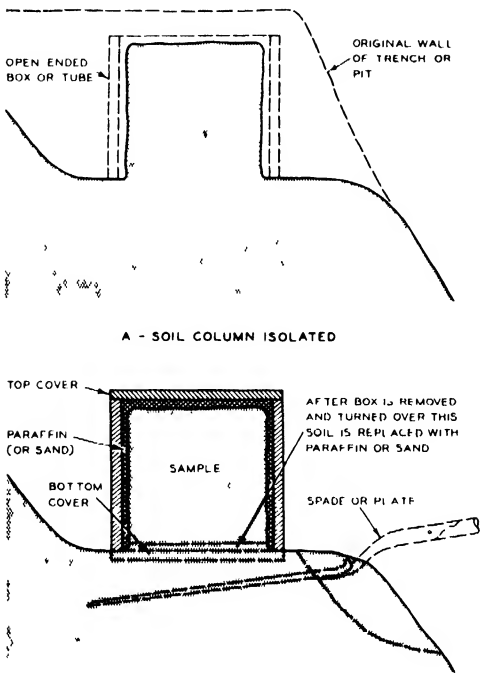
FIG. 134

Advance trimming relieves the residual stresses and may cause a slight expansion of the soil in the sample and a corresponding decrease of its unit weight when the soil is not fully saturated.

Samples from 4 to 8 in. in diameter are generally taken by this method. It is not as fast as drive sampling, but it causes less disturbance of the soil and can be used in stiffer and more brittle soils, however, it is not suited for sampling of hard and partially cemented soils, very soft soils, and soils consisting mainly of gravel and stones.

Block sampling.- A block or chunk of very stiff or partially cemented soils may be cut out and preserved by dipping it in paraffin or placing it in a suitable container. A wider application of this method is obtained by first isolating a column of soil and, before cutting it free, surrounding it with a section of tubing or a square

box without covers, and filling the space between the sample and the container with tamped fine sand or paraffin, Fig 136 A 10- to 12-in square box with easily dismantled sides and covers is often used, especially in block sampling of cohesionless soils A method which is intermediate between advance trimming and block sampling consists in using a shoe with decreased inside diameter for the sampler shown in Fig 134, so that there will be about 1/2-in clearance between the sample and the container This space is later filled with paraffin



A - SOIL COLUMN ISOLATED

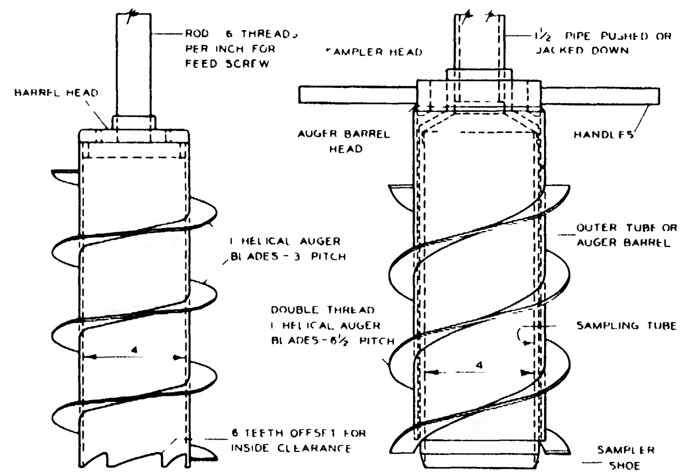
B - SAMPLE ENCASED

BLOCK SAMPLING

FIG 136

Isolation of the soil column will relieve the stresses in and may cause some expansion of the soil, but block sampling is the best available method for obtaining large undisturbed samples of very stiff and brittle soils, partially cemented soils, and soils containing coarse gravel and stones The method can be used in all soils except when cohesion, whether true or apparent, is so small that a soil column cannot be isolated

Auger core barrels.- Special rotary core barrels which do not require circulation of water or drilling fluid for removal of the cuttings have been used to a limited extent in surface sampling of soils



SLATER BYERS DEPT AGRIC BUL 231 1931

A - SINGLE TUBE BARREL

V R SMITH REPORT CALIF RESEARCH CORP 1944

B - DOUBLE TUBE BARREL

FIG 135 - AUGER CORE BARRELS

A single tube core barrel, developed by **Slater and Byers (733)**, is shown in Fig. 135A Slightly offset steel teeth cut the core with a diameter 3/8 in less than the inside diameter of the barrel A strip of steel is welded to the outside of the barrel to form a helical auger which serves to cut the annular groove and to transport the cuttings to the surface The rate of advance or feed is controlled by threads on the drill rod and a stationary feed screw attached to a supporting frame. The core barrel is withdrawn empty, and the core is recovered by lifting or digging it out In case of

soils with little cohesion, the annular space around the core is filled with paraffin before the core is recovered

. The recovery of the core is facilitated by use of the double tube auger core barrel shown in Fig 135B and developed by **V. R. Smith (964).** The inner tube is jacked down while the outer barrel with the helical auger is rotated, cuts an annular groove, and transports the cuttings to the surface The core is preserved in the inner tube The method is comparable to drive sampling with advance trimming. It is possible that the method, with certain modifications and further development, may be used to advantage in control sampling of strongly compacted but not too coarse-grained soils

4.21 Preservation and Shipment of Samples

The dismantling of the sampler or core barrel upon its withdrawal from the bore hole should be performed without shocks and blows which may cause disturbance of the sample The gross length and recovery ratio should be determined for soil samples and the net length and recovery for rock cores Any downward movement of the sample to actuate core retainers should be taken into consideration in determining the gross length If the lower part of a sample is lost, the length of the lost part should be determined and the probable cause of the loss recorded

Preservation of rock cores.- The cores should be thoroughly cleaned of sludge and drilling fluid Rock cores of small diameter are preserved and shipped in boxes of wood or sheet metal, divided into compartments which provide a snug fit for the core, whereas large rock cores generally are placed on racks near the borings Some rocks disintegrate on contact with air and free moisture, cores of such rocks should be given a coating of paraffin or clear lacquer, wrapped in Cellophane or Pliofilm, or placed in sealed containers The individual cores should be separated with wood blocks and properly marked

Preservation of representative soil samples.- Small representative samples are generally preserved in glass jars with a screw top and gasket When maintenance of the water content is not necessary, the samples may be preserved in wood boxes, in sheet metal or cardboard containers, or in tightly woven and double-stitched canvas bags

Preservation of undisturbed soil samples -- general.- Undisturbed soil samples, obtained by means of drive samplers or core barrels, should preferably be preserved in the sampling tube or in liners in order to avoid disturbances caused by removal and handling of the unprotected sample under adverse conditions in the field When the samples cannot be preserved in this manner, and when they are obtained by block sampling methods, they are usually given a coating of or encased in paraffin

Seriously disturbed parts of the sample should as far as possible be separated from the undisturbed parts in order to avoid a migration of pore water from the

disturbed to the undisturbed parts It is likewise desirable to separate coarse-grained from fine-grained sections of the sample to avoid migration of pore water from the former to the latter, but such a separation is possible only when the strata have considerable thickness and the sample is removed from the sampling tube or liner

Disturbed but representative sections, obtained by cutting or trimming large samples in preparing them for sealing, should be preserved in sealed glass jars Even when trimming of undisturbed samples is not necessary, it is often advantageous to cut out a small section from the top or bottom of each sample and to preserve the sections separately in glass jars Such small, representative sample sections permit examination and classification tests to be performed in the laboratory without breaking the seals of the undisturbed samples

There must be no clearance or voids between the sample and its container, since the air in such spaces expands and contracts with varying temperatures and pressures and increases the danger of leakage and drying besides promoting corrosion and growth of fungus When there is a definite circumferential clearance between the sample and the container, but it is too small to be completely filled with rapidly congealing paraffin, the sample should be transferred to a larger container and completely encased in paraffin

Control measurements and tests.- After the sample is trimmed for sealing, its net length should be carefully measured and recorded When large undisturbed samples are to be shipped by common carriers or over long distances and, in general, when it is possible that a considerable period of time may elapse between the sampling and the testing, it is also advisable to weigh the sample before and after sealing and to make structural control tests, such as cone penetration, squeeze, or unconfined compression tests on small test specimens cut from the undisturbed sample, see Section 16 13

Preservation of soil samples in paraffin.- Melted paraffin will penetrate into pervious soils and only samples of relatively impervious soils should be preserved in paraffin To decrease the penetration of paraffin, the sample should first be given one or two brush coatings of paraffin and then dipped repeatedly in the melted paraffin until the coating has a thickness of at least 0 1 in for small samples and 0 2 in for large samples The paraffin coating may be reinforced by wrapping the sample in cheesecloth between the dippings in paraffin Large samples are, however, generally placed in an oversize cardboard tube or a split sheet metal tube and melted paraffin poured around them so that a 0 5-in thick coat is formed, but the cast coating is not as tight or strong as that obtained by repeated dipping

Satisfactory protection of the sample can be obtained in the above mentioned manner when the work is carefully performed, but difficulties and defective sealing are often encountered in practical applications The paraffin is subject to considerable shrinkage during congealing and becomes brittle in cold weather There is always danger that voids or air-spaces and cracks will be formed during congealing

and shrinkage, especially at joints where melted paraffin has been poured on top of congealed and relatively cool paraffin The paraffin becomes soft and plastic at high summer temperatures, and the sample may then slowly sink down through the paraffin, thereby reducing the thickness of and even perforating the coating below the sample

The paraffin should be applied at a temperature as close as possible to its congealing temperature, and its physical properties can be improved to some extent by mixing several grades of paraffin having different melting and congealing temperatures and also by admixtures of ceresine, carnaubawax, or beeswax It is possible that better protection can be obtained by means of modern sealing compounds of rubber and plastic materials which can be sprayed on the sample

Sealing of samples in sampling tubes or liners.- As indicated, undisturbed soil samples should preferably be preserved in the sampling tube or in the liners of composite drive samplers or core barrels Unless the sample is to be tested within a few days after sampling, the tubing or liner should be of non-corrosive material or galvanized or coated on the inside with a hard and smooth lacquer

Samples in long, thin-wall sampling tubes or in long liners may be sealed with a plug at least 3/4 in thick of paraffin, beeswax, or battery sealing compound The latter provides the best seal since it is practically impervious, remains plastic and does not shrink, and has strong adhesion to other materials A paraffin plug should be reinforced with a metal disk embedded in the paraffin slightly above the surface of the soil, see Fig 330A When such a disk is not used, shrinkage cracks are likely to be developed between the plug and the tubing Beeswax does not shrink as much as paraffin and has stronger adhesion to metal, but it is not as tight as paraffin and should not be used when the samples are to be stored for protracted periods The sealing plugs should be reinforced with a plug of plaster of Paris when required to prevent expansion of samples of swelling soils

Short liner sections are sealed with caps which should be of the same metal as the liner or of electrically inactive materials in order to avoid electrolysis and chemical changes of the soil It is advisable to cover the top and bottom of samples of relatively impervious soils with a thin layer of paraffin and to place the cap while the paraffin still is liquid The joint between the cap and the liner should be sealed with adhesive tape and by dipping in paraffin or sealing compound The joint may also be sealed with a rubber band when the samples are to be tested within a few weeks after sampling When the sample consists of swelling soil, the caps should be secured in such a manner that expansion of the sample is prevented

Marking of samples or their containers.- All samples or containers should be clearly marked with the name or number of the project, boring and sample number, top or bottom of the sample, and preferably also with other essential information such as date of sampling, depths between which the sample is taken, type of material, method of sampling, gross and net lengths, and recovery ratios. When sectionalized liners are used, the individual sections should also be marked with a reference line

as they are removed from the sampler, so that they and the samples in the laboratory can be oriented in their original relative positions.

The reference line and numbers of project, boring, and sample may be written or painted on the paraffin coating or sample container with crayon, paint, or lacquer The numbers and further details are recorded on a label which is pasted on the paraffin coat or container, or on a tag which is attached to the container or bag. Duplicate labels or tags are often used, and the writing should be made with non-fading and non-washable ink and preferably protected by a coat of clear paraffin or lacquer The tag may also be protected by placing it in an envelope which, in turn, is attached to the container or bag

Packing and shipment of samples.- Representative samples should be packed for shipment in such a manner that the containers are protected against breakage and also against excessive moisture which may cause deterioration of labels or tags. Undisturbed samples should be protected, as far as possible, against vibrations and shocks. They should preferably be transported in private vehicles and placed in upright position in padded crates or on a mattress When undisturbed samples are to be shipped by common carriers, they should be packed in strong wooden boxes and surrounded with excelsior or sawdust. The samples should at all times be protected against freezing

Undisturbed samples of loose cohesionless soils are particularly sensitive to vibrations, and they cannot be shipped by common carriers without suffering some compaction and disturbance of the soil structure When such samples are intended for accurate laboratory tests, they should be transported in private and carefully driven vehicles, and they should preferably be tested in a laboratory close to the site of the borings

4.22 Handling of Samples in the Laboratory

The following review covers the storage and general examination and handling of samples in the laboratory up to but not including the preparation of soil specimens for physical tests

Inspection and storage of samples.- On arrival in the laboratory, identification tags or labels should be checked against the boring and sampling records, and the sealing of the samples should be carefully inspected and repaired or renewed as required

The samples should be stored in a cool but frost-free room and, insofar as possible, in upright position. If there is any doubt about the effectiveness of the sealing of the samples, they should be stored in a room in which the humidity is kept close to 100 percent, or they should be placed in boxes and surrounded with moist sawdust High humidity will retard loss of water but cannot prevent it, and it is better to seal the samples properly than to rely on storage in a humid-room or in moist sawdust to prevent loss of water.

In spite of all precautions, there is always danger that loss or internal migration of water and structural or chemical changes of the soil may occur during protracted storage, and the samples should therefore be tested as soon as possible after arrival in the laboratory When samples are removed from storage, the sealing and the general condition of the containers should again be inspected and any defects noted in the laboratory record The weight of the sealed sample should be determined if similar control tests have been made in the field or before placing the sample in storage

Removal of seals and short containers.- Paraffin coats should be divided into strips or squares by means of V-shaped cuts and removed in small sections. Attempts to remove too great sections at one time may cause parts of the sample to be torn off When the paraffin adheres strongly to or has penetrated slightly into the soil, the sample should be cut with a wire saw slightly below or inside the paraffin coat.

Plugs of paraffin or sealing compound can usually be removed from short containers by means of a screw driver or knife, but care must be taken not to disturb the sample Caps should be removed by pulling and prying rather than by tapping which may cause disturbance of samples of cohesionless soils. After removal of the sealing plugs or caps, the net length of the sample should be measured

When the liner is divided into small sections and the sample is to be tested without removal from these sections, it is simply cut with a thin wire saw at the joints between the sections.

When a container or liner is to be removed from the sample, the relative movements should be the same as during the sampling in order to avoid a reversal of the stresses induced by the inside wall friction. The lower end of the sample should be supported on a plunger capped with a close fitting disk of cork or similar material, and the container should be removed by a steady axial pull. It is very important that the lower end of the sample is plane and at right angle to the axis of the container, since the pressure from the plunger otherwise will cause plastic deformations and serious disturbance of the lower part of the sample. The sample should be supported by a plate or semicircular trough in such a manner that distortions do not occur during and after removal of the container When jacking or great force is required to remove the container, it should be noted in the laboratory record, since it is likely to cause disturbance of the sample

The sealing of longitudinal seams in split liners should be cut or removed to relieve internal stresses in the sample, but the liner should be separated from the sample by an axial pull. Attempts to lift a half-section of a double split liner, or to open fully a split liner with a single seam, may cause breaking off of parts of and even splitting of the sample.

Removal of long containers.- Since samples preserved in long sampling tubes or liners cannot be removed as a unit without disturbing the sample, the tubes and

samples must first be cut into sections with a length of three to six times the diameter of the sample, depending on the magnitude of the internal friction and the adhesion between sample and container Before cutting the tubing, the various sections should be marked with the section number, top or bottom, and with a longitudinal reference line so that the sections later can be oriented in their original relative positions

To reduce vibrations to a minimum, the tubing should be firmly clamped and the cutting performed with a fine-toothed hacksaw or with a high speed carborundum wheel. The sample itself should preferably be cut with a wire saw. The cuts should be straight and at right angle to the axis of the tubing. The burrs along the inside edges of the cuts should be removed, and the lower end of each section should be trimmed if it is not plane and square with the axis of the tubing The tubing is thereafter removed in the same manner described above for short containers, and the exposed sample sections should be marked with sample and section number and a reference line.

Removal of samples of cohesionless soils.- It is very difficult to avoid some vibration and disturbance of samples of cohesionless soils when the tubing is cut into sections. When determination of the unit weight and void ratio of the various strata is the principal object, the tubing should not be cut into sections, but the sample should be removed in small increments, 1 to 2 in in height, by means of a close fitting cup auger, Fig 345 The height of each increment can be controlled by an adjustable stop collar on the auger rod Each soil increment is weighed and its original volume determined by the inside diameter of the tubing and the height of the increment.

Protection against drying.- All laboratory operations, preparatory to the actual testing, should preferably be performed in a humid-room In any case, sections of the sample not in actual use should be protected against loss of water by placing them in a container with airtight covers or by wrapping them in wax paper, but preferably in Cellophane or Pliofilm since the rate of loss of water through these materials is much smaller than through wax paper When sample sections are to be preserved for more than a few hours, they should be dipped in paraffin until a coating about 0 1 in thick is formed

Examination for disturbance.- The condition of the sample should be carefully investigated to determine if it is suitable for major physical tests and so that the least disturbed parts may be selected for testing The total recovery ratio should be taken into consideration, and the net length of the sample should be accurately measured before the tubing is cut into sections or removed from the sample and should be compared with the net length measured in the field. Whenever other control measurements and tests have been performed in the field, they should, of course, be repeated in the laboratory. The empty containers should be inspected for corrosion and adhesion of soil, and the surface of the sample should be examined for discolorations, pitting, cracks, and hard and soft areas.

Cross-sectional and longitudinal slices should be cut from the top and bottom sections of the sample and examined for planes of failure and distortions of the soil layers. The color contrast between the various strata can be increased by partial drying. The cross-sectional or horizontal slices require the least waste of sample material and are easy to prepare. They often permit direct determination of the strike of the strata, and concentric rings in such a slice indicate serious distortions, but the absence of rings does not guarantee that the sample is undistorted, since the cut may have been made entirely within a relatively thick and uniform soil layer. Horizontal slicing should therefore be supplemented by longitudinal slicing, which will expose distortions and planes of failure even when the soil layers are relatively thick, provided the soil is stratified

Even though there are no signs of distortions, the top and bottom sections of the entire sample will usually be partially disturbed during boring and sampling operations and should therefore not be used for major physical tests The individual sections of the sample will also be disturbed for a short distance from the places where the tubing and the sample have been cut, and the lower part of such sections may be seriously disturbed when the end of the sample has not been properly squared off and when great force is required to remove the tubing

Detailed soil profile.- When the detailed stratigraphical soil profile is to be determined in the laboratory, all the sample sections not used for major physical tests should be sliced longitudinally so that the character, thickness, and inclination of the various strata can be determined The cut should preferably be made in the direction of the dip or maximum inclination of the strata, at least, the cut in the various sections of a long sample should have the same orientation with respect to the reference line. The soil may appear uniform at its natural water content although it is stratified and there is considerable difference in the character of the various strata. To detect such stratifications and differences one-half of the samples, or slices from 1/2 to 3/4 in. thick, should be partially dried and trimmed with a sharp knife for further examination, whereas the remaining parts of the sample may be used for classification tests

The consistency of the soil is often judged by its feel alone, but much more reliable and consistent results are obtained by cone penetration tests or by squeeze or unconfined compression tests on small test specimens cut from the principal strata or the individual sample sections, see Section 16 13. When the diameter of the sample is small, these tests must be made before the slicing

Photographing soil samples.- Photographs of sliced and partially dried samples provide a permanent pictorial record of the soil profile and often show more details of stratifications and soil structure than can be seen in the sliced sample in its natural or completely dried state. In many cases it is also advantageous to slice and photograph sections of the sample adjacent to test specimens for major physical tests or to slice and photograph test specimens after the test. Such photographs materially assist readers of the test reports in forming a conception of the soil type

and structure and in estimating the condition of the sample and test specimen and the value of the test results.

The sample slices intended for photographing should preferably be from 1/2 to 3/4 in. thick, and they should be placed on paper towels or thick filter paper to insure even drying and to avoid cracking. The color contrast between the various strata increases with partial drying and reaches a maximum when the coarser strata pass the shrinkage limit and assume a lighter color The soil close to the surface of the slice is partially disturbed and details of the soil structure thereby obscured After partial drying but before the maximum color contrast is reached, the side of the soil slice to be photographed should be carefully trimmed with a sharp knife in order to remove the thin layer of disturbed soil Samples at maximum color contrast may be preserved in this state for several days by wrapping them in Cellophane.

CHAPTER 5
SAMPLING AND SOIL TYPES

5.1 General

In the foregoing review of the equipment and various methods used in obtaining samples of subsurface materials it has also been indicated in which types of soils each method or sampler can be used to best advantage. Information on the sampling methods which are suitable for use in various groups of soils is therefore scattered over several sections, and the purpose of this chapter is to assemble and amplify this information. A summary of the commonly used or most advantageous methods of boring and sampling for the principal stages of exploration in various groups of soils with similar characteristics is presented in Table 8 Such a summary entails, of course, considerable generalization, and further details, the difficulties encountered, and special precautions to be taken in securing undisturbed samples of soils in the various groups, are discussed in the following sections

5.2 Common Cohesive and Plastic Soils

This group embraces all common soils of medium to stiff consistency in their undisturbed state and with some degree of cohesion and plasticity, ranging from clayey, fine sand and silt to plastic clays and firm peat

These soils are fairly easy to explore and sample, and several methods of boring and sampling may be used without appreciable differences in the results obtained Depending on the consistency of the soil, uncased and dry bore holes can often be used for shallow depths, but stabilization with casing or drilling fluid is generally required when undisturbed samples are to be obtained through deep bore holes.

Undisturbed samples can be obtained with properly designed and operated open drive samplers and piston samplers Thin-wall samplers are preferable, but satisfactory samples can be obtained with composite samplers of large diameter, at least when a sampler with stationary piston is used This type of sampler, whether thin-wall or composite, will generally furnish the longest and least disturbed samples and has other advantages as outlined in Section 4 12. Core boring is occasionally used in the stiffer soils.

Satisfactory surface or control samples can generally be obtained with short, thin-wall drive samplers of either the open or piston type, but in relatively stiff and

TABLE 8 - SAMPLING AND SOIL TYPES

TYPE OF SOIL	METHODS OF BORING	RECONNAISSANCE EXPLORATIONS REPRESENTATIVE SAMPLES	DETAILED EXPLORATIONS SMALL UNDISTURBED SAMPLES	SPECIAL EXPLORATION LARGE UNDISTURBED SAMPLES	SURFACE SAMPLING UNDISTURBED SAMPLES CONTROL SAMPLES
	Methods shown in parentheses are rarely used	Sampling in Borings of each Significant Stratum but 5 ft maximum spacing	Sampling in Borings Continuous Samples Diameter 2 to 3 In	Sampling in Borings of Controlling Strata Diameter 4 to 6 In	Sampling Close to Surface Accessible Explorations Earth Structures
Common Cohesive and Plastic Soils	Displacement Wash Auger Continuous Sampling (Percussion Rotary)	Augers 1 to 2 In. Piston or Open Drive Sampler	Thin-Wall Drive Sampler Open or with Stationary or Free Piston	Thin-Wall or Composite Drive Sampler with Free or Stationary Piston (Cut Wire, Vacuum Relief)	2 to 6 In Thin-Wall Open Drive or Free Piston Sampler 4 to 8 In Adv Trim Sample 8 to 12 In Sq Box Sample
Slightly Cohesive and Brittle Soils including Silt, Loose Sand above Ground Water	As above but keep boring dry for undisturbed sampling above ground water	As above	As above	Thin-Wall Drive Sampler Free or Stationary Piston (Vacuum Relief)	As above but advance trimming or box sampling preferable
Very Soft and Sticky Soils	Displacement Wash Bailers, Sandpumps Continuous Sampling (Auger Rotary)	Slit or Cup Sampler 1 to 2 In Piston or Open Drive Sampler (Core Retainers)	Thin-Wall Drive Sampler with Stationary Piston	Thin-Wall or Composite Drive Sampler with Stationary Piston Vacuum relief required	2 to 6 In Thin-Wall Open Drive or Sta Piston Sampler Danger of soil movements and disturbance before sampling
Saturated Silt and Loose Sand	Displacement, Wash Bailers Sandpumps Continuous Sampling (Rotary)	As above Release stat piston before any intentional overdriving	Thin-Wall Drive Sampler Free or Stationary Piston 2 In Diameter	Thin-Wall Drive Sampler Free or Stationary Piston Vacuum relief or freezing bottom of sample required	2 to 6 In Thin-Wall Sampler Open or Free or Sta Piston 4 to 8 In Adv Trim Sample Depress ground water level
Compact or Stiff and Brittle Soils including Dense Sand Partially Dried Soils	Wash, Augers Percussion Rotary Continuous Sampling	Augers and 1 to 2 In Thick-Wall Piston or Open Drive Sampler	Medium-Wall Open Drive or Piston Sampler Hammering may be required (Partial Disturbance)	Core Boring may be better than Drive Sampling but danger of contamination in partially dry soils	4 to 8 In. Adv Trim Sample 8 to 12 In Sq Box or Block Samples Auger Core Boring Bag Sample and Field Density
Hard, Highly Compacted or Partially Cemented Soils, no Gravel or Stones	Percussion Rotary Continuous Sampling	Thick-Wall Open Drive Sampler Core Boring	Thick-Wall Open Drive or Piston Sampler Core Boring Samples small diam often partially disturbed	Core Boring preferable to Drive Sampling Danger of fluid contamination in permeable soils	8 to 12 In. Sq Box Samples or Irregular Block Samples
Coarse Gravelly and Stony Soils including Compact and Coarse Glacial Till	Percussion, Barrel Auger Loosen by Explosives Thick-Wall Drive Sampler	Barrel Auger Thick-Wall Drive Sampler (Core Retainer)	Not practicable	Advance Freezing then Core Boring	8 to 12 In Sq Box Samples Bag Sample and Field Density
Gaseous or Expanding Soils (Organic Soft Clay, Silt, Sand)	According to soil but keep boring filled with water or drilling fluid	As above according to basic soil type	Thin-Wall Sampler with Free or Stationary Piston. Force closed sampler through expanded soil Determine original sample length and volume Sealing to prevent expansion		Thin-Wall Drive Sampler Open or Piston Type Danger expansion of soil before sampling
Gradual or Sudden Changes in Soil Properties within a Single Drive	As above according to basic soil type	As above according to basic soil type	Safe length of sample increased when progressing from weak to firm strata and vice versa Thin soft strata often disturbed. Withdraw after passing firm stratum		As above according to soil type When possible separate coarse and fine-grained soil
Soils with Secondary Structure	As above according to basic soil type	As above according to basic soil type	As above according to basic soil type, but the results of strength, consolidation, and permeability tests do not always represent properties of undisturbed deposit		Large Box or Block Samples Large test specimens Detail field tests and observations

brittle soils there is less danger of disturbance when advance trimming or box sampling methods are used.

The physical properties of this large group of soils vary within very wide limits, and to obtain best results, the inside clearance and the depth of penetration of the sampler should be varied in accordance with the character of the soil. The samples can usually be retained without difficulty when the diameter is less than 3 in., but for samples of large diameter it may be necessary to prevent formation of a vacuum below the sample or to use a snare wire to cut samples of tough soils free from the subsoil

5.3 Slightly Cohesive and Brittle Soils

Silt and fine sand with a small amount of clay or other cementation, such as loess, and partially saturated silt and loose sand with some apparent cohesion fall in this category.

Borings in partially saturated soils should be kept dry or, when necessary, filled with drilling fluid instead of water. When casing is used, it should be advanced without vibrations and never ahead of the bore hole

Samples of these soils can usually be obtained without difficulty by means of open drive samplers or piston samplers, but sampling tubes with very thin walls should be used since the soil structure is easily disturbed by displacement of soil. Samplers with a stationary piston will usually furnish the longest and least disturbed samples and also decrease the danger of losing the sample. Samples up to 3 in in diameter can generally be retained without difficulty, but for samples of large diameter it may be necessary to prevent formation of a vacuum below the sampler Core boring is occasionally used in these soils and outwardly satisfactory samples obtained, but it is an open question whether the whip and vibrations of the core barrel do not cause greater disturbance than the displacement of soil by a thin-wall drive sampler

Some clays appear to be very brittle although only of soft to medium consistency, and the samples often contain planes of failure Very thin-walled samplers with stationary piston should also be used in obtaining undisturbed samples of these soils.

Short open drive samplers or piston samplers with thin walls are often used in surface and control sampling of relatively soft and loose brittle soils, but there is less danger of disturbance when the advance trimming or block sampling methods are used.

Samples to be used for major laboratory tests should not be removed from the sampling tube in the field, and great care should be taken to avoid shocks and vibrations during transportation of the samples. The unavoidable vibrations during transportation with common carriers will often cause disturbance of the samples.

5.4 Very Soft and Sticky Soils

This group includes very soft clays, soft peat, organic silt, and various mixtures of these soils or fine sand with decayed organic matter often found in rivers, estuaries, tidal flats, and harbors, and commonly called mud or ooze

To prevent caving of bore holes in these soils, it is generally necessary to use casing and to keep it filled with water or drilling fluid. Even then the soil below the bottom of the hole is often in a state of impending failure, and excess soil may enter an open drive sampler during the first part of the drive. However, these soils are often sticky and subject to great lateral deformation, so that the inside friction and adhesion quickly are developed, even when there is considerable clearance at the cutting edge After a short length of sample has entered the sampler, the inside friction may reach such a magnitude that soil below the sampler is pushed aside instead of entering the sampler, unless pressure over the sample is reduced or full development of inside friction and adhesion is prevented by a high speed of penetration

As demonstrated in explorations of the ocean bottom, Section 12.2, long samples of soft and sticky soils can be obtained with open drive samplers provided the sampler is forced into the soil at great speed and has streamlined vents with a cross-sectional area equal to that of the sample, so that an excessive increase in the hydrostatic pressure over the sample is prevented. However, these requirements are difficult to fulfill when the sampling must be performed through bore holes of relatively small diameter.

The best means of obtaining samples of soft soils is undoubtedly a piston sampler with stationary piston Samples with a diameter of 2 in. and a length of 3 to 4 ft have consistently been obtained with such samplers, even of extremely soft and sticky soils, Fig. 225. When the sample is 3 in or more in diameter, it is generally necessary to maintain or increase the pressure below the sampler during withdrawal in order to prevent loss of the sample. Even with this precaution, samples of large diameter may be lost on account of progressive internal failure unless they are supported by core retainers

Advance trimming and box sampling methods cannot be used to advantage in surface and control sampling of these soils, and samples are best obtained by means of short, thin-wall drive samplers of either the open or stationary piston type. However, it must be borne in mind that in sampling at appreciable depths in test pits and other accessible explorations, the soil may be partially disturbed before sampling because of unavoidable stress changes and plastic deformations, and it is possible that less disturbed samples can be obtained in bore holes which can be kept filled with water or drilling fluid.

5.5 Saturated Silt and Loose Sand

This group consists of inorganic silt and loose to medium dense sand when

found below ground-water level

The bore hole may in some cases be stabilized with drilling fluid, but casing is generally required and should be kept filled with water Vibrations should be avoided, and the casing should be advanced by rotation, jacking, and jetting when undisturbed samples are desired

It is questionable whether undisturbed samples can be obtained by means of core boring. These soils are easily eroded, and their internal structure may be disturbed and the void ratio decreased by the whip and vibrations of the core barrel. Core retainers are usually required and may cause additional disturbance of the sample, and they are not always effective in preventing loss of fine-grained cohesionless soils unless they completely close the lower end of the inner tube

Relatively undisturbed samples can be obtained with drive samplers of tubing with very thin walls Samplers with a free or stationary piston are preferable to open drive samplers, since they permit accurate determination of the recovery ratios. A sampler with stationary piston will provide longer and possibly less disturbed samples than one with a free piston, but great care should be taken not to create a void over the sample by exceeding the safe penetration, since the consequent upward flow of water through the sample may cause piping and serious disturbance of the soil, Fig. 96A

The inside friction is usually sufficient to retain the sample, and samples up to 2 in. in diameter can often be retained in piston samplers when the withdrawal is slow and care is taken to avoid shocks and vibrations. Injection of compressed air below the sampler or advance and cleaning of the casing before withdrawal may prevent loss of samples up to 3 in in diameter, but the method is not always reliable since progressive internal failure and gradual loss of the sample may occur when the diameter is large It is possible that the samples may be retained by closing the top of the casing and forcing the water out by, and performing the sampling under, compressed air, Section 11 10 The most positive method, so far developed, for preventing loss of samples of saturated, loose, cohesionless soils, consists in freezing the lower part of the sample before withdrawal; see Section 11 8.

Fine sand and silt deposits occasionally have such a large void ratio and unstable structure that the advance of even a very thin-walled sampler may cause collapse of the soil structure, partial liquefaction of the soil, and decrease of the void ratio Undisturbed samples of such extremely loose soils may be obtained by increasing the viscosity of the pore water through cooling without actual freezing before sampling, Section 11 9.

Before the start of undisturbed sampling in test pits and other accessible explorations, the ground-water level should be depressed below the bottom of the samples to be taken, so that the soil will be under capillary pressure and acquire some apparent cohesion. Thin-wall drive samplers or advance trimming may thereafter be used depending on the density of the soil and the apparent cohesion developed.

Extreme care must be taken to avoid shocks and vibrations during the transportation and handling of undisturbed samples of loose cohesionless soils, which preferably should be tested in a laboratory close to the site under exploration.

5.6 Compact or Stiff and Brittle Soils

This group includes very dense sand, very stiff and brittle clays, clayey, silty, and sandy soils which have been strongly compacted or have acquired considerable cohesion through partial drying.

Although frequently used, casing is seldom required and stabilization of the bore hole with water or drilling fluid is generally adequate. However, the bore hole should be kept dry, insofar as possible, when undisturbed samples of partially saturated or dried soils are to be obtained. In any case, the bore hole should not be filled with clear water but only with viscous drilling fluid

Samples of these soils can be obtained with open or piston type drive samplers, but large pressures or hammering may be required to force the sampler into the soil, especially when dense sand is found at considerable depth below the ground surface. Samples of permeable or partially saturated soils may thereby be subjected to compaction, and samples of brittle soils are often disturbed by shear failures.

It is probable that less disturbed samples can be obtained by core boring, at least when the soil is relatively impervious and a viscous drilling fluid is used. However, there is danger that even such a drilling fluid may penetrate into and contaminate samples of permeable and partially saturated or dry soils. This danger might be avoided by use of auger core barrels in dry bore holes, but this type of core barrel has not yet been adapted for use in deep bore holes. Samples of cohesive soils can be retained without difficulty, but core retainers are generally required to prevent loss of samples of sand, although dense sand is much easier to retain than loose sand and silt.

In accessible explorations undisturbed samples should preferably be obtained by advance trimming or box sampling methods or by auger core boring. Short and fairly thin-walled drive samplers are often used in control sampling and when the primary object is to determine the natural density of the soil, but samples obtained by this method are often subject to minor changes in density when the soil is permeable or not fully saturated. When drive sampling is resorted to as a matter of convenience, possible errors and corrections should be determined by a series of control tests on samples obtained by other methods of surface sampling.

5.7 Hard and Partially Cemented Soils

This group comprises hard and brittle clays, partially cemented soils, such as marl and hardpan, and highly compacted glacial till without an appreciable content of gravel and stones.

Advance of the bore hole is relatively slow, and it is generally necessary to use percussion or rotary drilling Continuous sampling is often faster than percussion drilling. Difficulties due to actual caving are seldom encountered, but stabilization with drilling fluid or casing maybe required to prevent a gradual squeezing-in of deep bore holes.

Samples can be obtained by means of drive samplers with fairly thick walls, but it is necessary to force these samplers into the soil by means of hammering, and the safe depth of penetration is usually small Although the outward appearance of the samples may be satisfactory, numerous shear failures are often revealed by close examination. Longer and less disturbed samples can in most cases be obtained by core boring Block sampling methods should be used for obtaining undisturbed samples in accessible explorations

5.8 Coarse Gravelly and Stony Soils

Clean gravel deposits and soils containing considerable amounts of gravel and stones, such as coarse glacial till, fall in this category.

The advance of the bore hole is difficult, wash boring cannot be used, and rotary drilling is inefficient in these soils Borings in loose gravelly soils may be advanced by displacement boring or with augers, whereas percussion drilling is used to loosen compact deposits, whereupon the soil is removed with bailers, sand-pumps, or barrel augers Continuous sampling with heavy-walled drive samplers has been found advantageous in some cases and is occasionally used in combination with a preliminary loosening of the material by means of explosives

Representative samples of clean gravel are generally obtained with barrel augers As indicated above, a heavy-walled drive sampler can be used in stony soils, but it must be driven into the soil by means of a drop hammer, and the cutting edge is often damaged. The stones are pushed aside or into the sample, which therefore may be seriously disturbed Efforts to obtain samples of unsolidified gravel by means of core boring have failed. Samples of compact and stony soils containing some cohesive material can be obtained by core boring, but the stones tend to roll under action of the coring bit instead of being cut and are ultimately pushed aside or into the core barrel.

Undisturbed samples of these soils can be obtained by freezing the soil below the bottom of the bore hole and subsequent core boring. The method is expensive, but it is the only satisfactory one so far developed. Only block or box sampling methods should be used in accessible explorations.

5.9 Influence of Air and Other Gases in the Soil

The danger of compaction of the soil on account of increased stresses and vibration during the sampling operation is much greater for partially saturated than

for fully saturated soils. When the air is entrapped in the form of individual bubbles, it cannot escape when it tends to expand upon a decrease in external stresses and pore-water pressures. The soil will therefore be subject to swelling without a corresponding change in water content when it enters a sampler with an excessive inside clearance and when the sample is removed from the sampling tube or liner. Such an increase in volume without a change in water content may be called expansion to distinguish it from swelling caused by an increase in water content.

Expansion of the soil may be caused not only by air entrapped in the pores but also by air and other gases which are dissolved in the pore water and are released and expand when the pore-water pressures and soil stresses are decreased (*) This phenomenon was first observed and its cause suggested by the late **D. E. Moran (342).** It occurs primarily in soils containing organic matter, but the pore water in inorganic soils may also contain dissolved gases as a result of seepage from organic deposits. Numerous gas bubbles, about 1/16 in in diameter, can be seen in Fig. 105 which is a photograph of a sample of stratified sand, silt, and clay, taken from a depth of 57 ft on lower Manhattan Island

The gases may consist of air, hydrogen sulphide, carbon dioxide, methane, and other gases of organic origin. About 80 percent of the gases in samples of organic silt from New York Harbor -- analyzed by Professor E. Moore, Graduate School of Engineering, Harvard University -- were found to be carbon dioxide The volume of the released gases, reduced to atmospheric pressure, may exceed the original volume of the sample, and an increase up to 7 percent in length of the sample, caused by gaseous expansion, has been observed in several instances. Although the major part of the expansion may take place within a few hours after the stress reduction, it may continue at a decreasing rate for days and even weeks and months on account of a gradual release of the gases and/or the viscosity of the soil and restraining effect of the container in which the sample is preserved. The pressures developed are strong enough to break a 1/2-in coating of paraffin and to move sealing plugs or caps of sampling tubes or liners unless special precautions are taken to prevent such displacements.

Laboratory tests often indicate the presence of a small amount of air in soil samples, and it has been suggested that no soil is completely saturated. However, it is possible that the soil in situ actually is fully saturated, and that the air found in the samples originally was dissolved in the pore water and was released during the

(*) The amount of gas which free water can absorb depends on the coefficient of absorption for the particular gas and on the partial gas pressure at the interface between gas and water The pressure in a gas bubble depends on the hydrostatic pressure in the surrounding water, the surface tension, and the diameter of the bubble In a fine-grained soil the surface of a gas bubble is probably not uniform but consists of innumerable menisci over pores in the soil, and the expansion and contraction of such a bubble causes plastic deformations in the soil Therefore, it is probable that the amount and rate of release and expansion or re-absorption and compression of gas in soil depend not only on the pressures in the pore water and gas bubbles but also on the effective stresses in and strength of the soil and on the rate of plastic deformations Furthermore, the influence of capillary tension and the altered properties of water close to particles of clay minerals on absorption and release of gases is not yet known

actual sampling or subsequent handling of the sample.

A decrease of hydrostatic pressures and stresses in the soil in situ by excavations or by lowering of the ground-water level may cause release and expansion of gases in the soil and pore water and may thereby affect the stability of the soil and the settlement of subsequently erected structures. Gaseous expansion of soil samples may cause partial disturbance of the soil structure and will affect the results of laboratory tests to determine the strength and consolidation characteristics and other physical properties of the soil, see Section 6.4. Expansion of samples of gaseous soils cannot be entirely prevented but should be reduced to a minimum, and the original volume and degree of saturation of the sample should be determined as accurately as possible.

Some gaseous expansion may take place before sampling within the bulb of reduced stresses below the bottom of the bore hole, which therefore should be kept filled with water or drilling fluid. This precaution cannot be taken, and the zone of decreased stresses is much more extensive, in accessible explorations in which considerable expansion may take place before the actual sampling.

The samples should preferably be taken with a piston sampler which should be pushed into or through the zone of decreased stresses before the actual sampling is started. Samplers with either a free or stationary piston may be used. The latter type is preferable for sampling of soft and sticky soils, but care should be taken not to create a void over the sample by exceeding the safe depth of penetration, thereby permitting longitudinal expansion of the sample. It is also desirable to prevent formation of a vacuum below the sampler during withdrawal. The inside clearance should be small but not entirely eliminated. The clamping unit should be so constructed that the piston rod clamp can be released temporarily, Fig. 208, so that the length of the sample can be verified and the original volume of the soil determined before withdrawal of the sampler. Any expansion during withdrawal should be observed, and the ends of the sample should be trimmed and the net length determined as soon as possible after withdrawal. The samples should be preserved in the sampling tubes or liner, which should be sealed in such a manner that expansion of the soil during shipment and storage of the sample is prevented. It is possible that vibrations during shipment will increase the release of absorbed gases.

The problem of preventing release, expansion, or escape of gases entrained in soil and rock samples has been given serious consideration by petroleum engineers and geologists. The quantity and pressure of gases in oil sands may be very high, and erroneous estimates of the productive capacity of oil bearing formations are obtained when the gases are allowed to escape or to expand and change the void ratio of the material before the sample can be tested in the laboratory. Two core barrels have been developed which at the start of the withdrawal are closed by means of valves so that the pressure of fluid and gases in the pores is maintained at a value approximating the hydrostatic pressure of the drilling fluid at the bottom of the hole; see Section 14.4. It is doubtful that these pressure core barrels in their

present form can be used to advantage in soil sampling for civil engineering purposes, but the principles embodied in their design deserve consideration.

5.10 Influence of Changes and Stratifications

A gradual increase in strength and stiffness of the soil with depth, which often occurs in soft surface deposits, facilitates sampling. The safe depth of penetration is greater, and the danger of losing the sample is smaller than in uniform soft soil. Likewise, the recovery ratio increases and longer samples of soft soil can be obtained immediately above or when approaching stiff strata.

A gradual decrease in strength with depth, often encountered after passing dessicated or relatively firm or coarse surface deposits, decreases the safe penetration and increases the danger of losing the lower part of the sample. The effect of a sudden change from stiff to soft soil during a sampling operation depends on the length of the sample at the moment the stiff stratum is penetrated. When this length and the total inside friction are small, then an excess amount of soil may enter an open drive sampler on account of the increased load on the soft soil caused by the outside wall friction between the sampler and the overlying stiff stratum. On the other hand, when the length of sample of stiff soil exceeds a few times its diameter, then it is likely that the inside wall friction and the corresponding pressure on the soil below the sampler are so large that the soft soil layers will be deflected downward and may even be pushed aside instead of entering the sampler. Whenever there is a sudden decrease in penetration resistance, it is therefore advisable to withdraw the sampler and remove the sample of stiff soil before attempting to take a sample of the underlying soft soil.

When the soil consists of alternating, relatively thin layers of soft and stiff soil, as in varved clays, the safe penetration will often be smaller than in uniform soil. After the safe penetration is exceeded, the softer soil layers will be subject to greater deformations and a greater decrease in thickness than the stiffer layers, and they may to a large extent be pushed aside and the remnants mixed with broken parts of the stiff layers, see Fig. 99 and 108. Samples of such soil should be taken with a sampler with stationary piston, in which the automatic regulation of the pressure on top of the sample to some extent will compensate the change in consistency of the strata.

When the external forces on a sample of stratified soil are eliminated and the internal stresses primarily are governed by the capillary forces or menisci at the surface of the sample, a migration of pore water from the coarse-grained to the fine-grained soil layers may take place, see Section 6.3. **Samples of stratified soils** should be preserved in the sampling tube or in liners rather than in paraffin, since the confining forces of the tubing to some extent will replace the stresses which acted on the sample in situ. When the sample is removed from the sampling tube in the field or is taken in an accessible exploration, thick strata of sand and silt should,

as far as possible, be separated from thick clay strata before sealing.

Stratifications in rock with material difference in hardness and strength of the constituent strata increase the difficulties of core boring, since the best cutting medium, bit setting, and core catcher for one material may be inefficient or entirely unsuitable for another material These difficulties are increased when the strata have a pronounced dip, in which case the boring tends to change its direction until it is either parallel with or perpendicular to the strata The result is that the cores often are broken up and block the core barrel so that only short cores are obtained, and the danger of losing the lower part of the core is also increased when the bit setting and core catcher are unsuitable for the particular material.

5.11 Influence of Secondary Structure

Some soils and primarily stiff clays often have a secondary structure consisting of hair cracks, joints, or slickensides. Aside from occasional loss of the lower part of the sample, the secondary structure in soils seldom causes serious difficulties in sampling, but the results of laboratory tests to determine the physical properties and especially the strength and permeability of soils with secondary structure may not represent the actual values for the soil in situ. The average strength of a fissured soil is generally smaller and the permeability larger than that of the parent material Furthermore, these properties may be subject to considerable although slowly progressing changes when the stress conditions are altered, for example by excavation of soil.

The laboratory tests will furnish too low a strength when planes of failure in the test specimen follow joints or slickensides and too high a strength when planes of failure and joints intersect each other and when the test specimen is cut from a block without secondary structure Fairly reliable results may be obtained when the joint spacing is small compared to the dimensions of the test specimens, but even then it should be realized that some soils with secondary structure seem to gain in strength by partial disturbance and remolding, see Section 6 5. When the joint spacing is relatively large, recourse must be taken to large-scale field tests on the soil in situ and to observations of the behavior of completed structures of or founded on the soil.

The presence of joints, fissures, and other irregularities in rock will increase the difficulties in obtaining satisfactory cores. Broken rock is often ground up and removed by the circulating water or drilling fluid, or it may block the core barrel after the core has reached a relatively short length. In such rock the bit speed and feed and the pump discharge must be very carefully regulated, and it is advisable not to attempt to take too long cores and, whenever possible, to use core barrels of large diameter In order to obtain undisturbed cores of badly fissured rock as in fault zones, it may be necessary to solidify the material by freezing before the core boring.

CHAPTER 6
DISTURBANCE OF SOIL SAMPLES

6.1 General

Various causes and outward manifestations of disturbances to which soil samples may be subjected before, during, and after the actual sampling have been discussed in the foregoing chapters. Although most of these disturbances can be avoided or reduced in extent or degree by use of appropriate methods and equipment and careful work, ultimately the external stresses on the sample will be reduced from those acting in the ground to atmospheric pressure, and the soil in the sample may be subject to minor volume changes and some disturbance of the soil structure. The object of this chapter is to discuss the basic types of disturbance and their influence on the results of the major physical tests in order to arrive at a better understanding and a closer definition of the requirements for practical undisturbed soil samples.

The disturbances to which soil samples may be subjected can be classified in the following basic types, proceeding from relatively slight and common disturbances to grave and usually avoidable disturbances.

A. Change in stress conditions
B. Change in water content and void ratio
C. Disturbance of the soil structure.
D Chemical changes.
E. Mixing and segregation of soil constituents

The influence of these disturbances on the results of laboratory tests depends not only on the type and degree of disturbance but also on the character of the soil and the testing technique and is subject to extreme variations. Sufficient experimental data are not yet available for formulation of definite rules for determination of the influence of disturbances and the corresponding correction of test results, and the following discussion is limited to a review of general principles and trends. Some quantitative data are given by **Casagrande (907), Terzaghi-Peck (246), and Rutledge (963).** The last mentioned paper and the discussions thereof contain experimental and theoretical data for determination of the influence of sample disturbance and suggestions for correction of the results of laboratory test.

6.2 Stress Conditions in the Ground

The stresses acting on a small element of saturated soil in the undisturbed

ground are shown in Fig 137A. It is assumed that the soil is uniform and dry above the ground-water level The total normal stresses, σ_v and σ_h, are composed of the hydrostatic pressure in the free pore water or neutral stress, u, and the effective stresses, p_v and p_h The latter two represent the stresses between the soil grains or between the films of bound and partially solidified water surrounding the soil grains, they refer to the total areas of the element and not to the actual areas of contact, which are exceedingly small

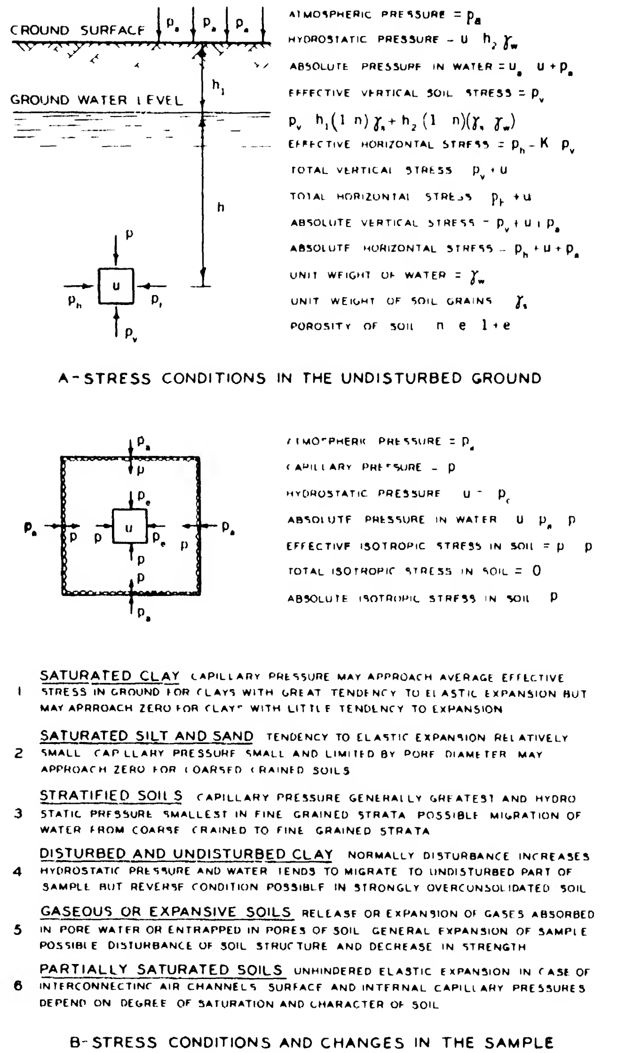


FIG 137-INFLUENCE OF CHANGES IN STRESS CONDITIONS

Since the free pore water cannot transmit shearing stresses, the total and effective shearing stresses in the soil are equal The conditions of failure are governed by the effective stresses, the coefficient of internal friction, and the bond between the particles The shearing resistance corresponding to this bond is called the cohesion It is not a constant for a given soil but varies with the void ratio and the stress history of soil and may be altered by disturbance of the soil structure

The ratio $K = p_h/p_v$, not to be confused with σ_h/σ_v, is generally assumed to be equal to the coefficient of the hydrostatic earth pressure at rest for the particular material, but little is known about its actual value in undisturbed deposits Laboratory experiments by **Kjellman (944, 945)** and observed deformations and planes of failure in undisturbed deposits indicate that the value of K depends not only on the character but also on the stress history of the soil, and that it may assume values between those corresponding to the active and to the passive earth pressure Furthermore, when the deposit has been subjected to one-directional geological forces and deformations, the horizontal stresses may not be equal in all directions These facts must be borne in mind when the stress conditions in the sample or test specimen are compared to those in the soil in situ, and when it is attempted to reestablish the original stress conditions during laboratory tests.

6.3 Change in Stress Conditions

The sample may be subjected to both stress increases and decreases during the boring and sampling operations By use of proper methods and equipment, stress increases which cause significant volume changes and disturbance of the soil structure can usually be avoided, at least for the major part of the sample, but a reduction of the total stresses to atmospheric pressure cannot be prevented when the sample is removed from the sampling tube or liner and during the preparation of test specimens The following discussion is concerned only with the consequences of such a reduction of the total stresses to atmospheric pressure

Capillary forces -- general.- When the soil sample is removed from its position in the ground and exposed to atmospheric pressure, the original external stresses will to some extent be replaced with capillary forces at the surface of the sample, but opinions differ in regard to the magnitude of these forces On one side it is maintained that, since the deformations of the soil mainly depend on the effective stresses and since the volume and void ratio remain practically constant, the stress produced by the capillary forces must be nearly equal to the average effective, normal stress on the soil specimen in situ On the other hand, the opinion has been expressed that the behavior of soils during consolidation and other tests indicates that the capillary forces are very small Both contentions are based on indirect evidence, and it is difficult experimentally to separate the influence of the stress reduction from that of a slight disturbance of the soil structure Reliable, direct measurements of the capillary forces acting on an exposed soil sample have not yet been made It is probable that the ratio between the original effective stresses and the capillary forces varies between wide limits and an attempt to explain such variations is made by the following hypothesis

The stresses acting on the soil in the ground cause elastic deformations of the soil grains and a corresponding amount of elastic energy is stored in the soil A reduction of the total stresses to atmospheric pressure will first of all cause a decrease of the pore-water pressure and a very small increase of the volume of the sample Since the compressibility of water is much larger than that of the mineral soil grains, the void ratio will be increased This change in void ratio is exceedingly small when computed on the basis of the compressibility of water at or above atmospheric pressure However, the compressibility increases rapidly with decreasing pressure, and the pore-water pressure in an exposed soil sample is smaller than atmospheric pressure and may, nominally, even be negative Furthermore, even a very small increase in void ratio may release a considerable part of the elastic energy stored in the soil when the upper part of the pressure-void ratio curve is very flat On account of the remaining elastic energy, there is a tendency to further expansion, which cannot take place without an increase in water content or admission of air to the pores of the soil Water menisci will then be formed at the surface of the sample and capillary forces created, which will balance the remaining expansive forces in the soil The original effective stresses will thereby be replaced by

effective, normal stresses with an intensity which is equal in all directions and depends on the original stress condition, the stress history, and the character of the soil A summary of the probable effects of the stress reduction for various soils and conditions is given in Fig 137B, and these effects will be discussed in greater detail in the following paragraphs

Saturated clay.- Fully saturated clays and other fine-grained soils with a large content of flaky mineral particles, which have been subjected to considerable volume changes and deformations after the formation of the deposit, often have a great tendency to expansion Capillary pressure and effective stresses in the removed sample may then be of considerable magnitude and may even approach the average effective stress in the undisturbed deposit, provided the sample has not been subject to structural disturbance On the other hand, many clay deposits show very little change in water content with depth, they have not been subject to material deformation and have but little tendency to expansion In this case the initial expansion of the pore water may release a major part of the elastic energy stored in the soil, and the capillary forces will be very small and may even approach zero However, the strength of the soil may not be materially affected thereby since it primarily depends on the bond between the particles

The change in stress conditions will undoubtedly cause a decrease of the shearing resistance, as determined by unconfined compression tests, but it is probable that this decrease in many cases will be very small This conclusion is supported by the fact that there often is very little difference between the unconfined compressive strength and that determined by unconsolidated, quick triaxial tests, as reported in the review of the results of the Cooperative Triaxial Shear Research by the Corps of Engineers (116) The influence of temporary stress reduction on results of consolidation, direct shear, and triaxial tests is probably smaller than for unconfined compression tests and may be interpreted as a hysteresis effect This effect should be very small or negligible when the sample is subjected to stresses in excess of the original stresses in the ground

Saturated coarse-grained soils.- Cohesionless soils without a material content of mica and other flaky minerals are subject only to very small volume changes and elastic deformations upon a reduction of the total stresses, and a major part of the elastic energy stored in the soil may be released by the initial expansion of the pore water Furthermore, the water menisci are generally drawn into the soil and air is admitted to the outer pores, causing the sample to expand until the effective stresses are reduced to the possible maximum value of the capillary pressure, which is governed by the diameter of the pores in the soil The effective stresses will generally be reduced to such an extent that the results of unconfined compression tests cease to have any practical meaning However, the temporary stress reduction will probably not have any material influence on the results of other laboratory tests, provided the soil structure has not been disturbed

Stratified soils.- When a sample consists of alternating layers of fine- and

coarse-grained soils, it is probable that the capillary forces and the corresponding reduction of the pore-water pressures, caused by exposing the sample to atmospheric pressure, will vary from layer to layer. An internal migration of water will then take place until the pore-water pressures have been equalized throughout the sample or the water menisci have been drawn into and air admitted to the pores of the coarse-grained soil layers. It has been observed that the clay layers in samples of some stratified soils have absorbed most of the water in the sand and silt layers, **Kimball (942).**

Disturbed and undisturbed clay.- Disturbance of the soil structure of clayey soils will usually cause a decrease in strength and an increase in consolidation under a specific load. A partially disturbed sample of such a soil, exposed to atmospheric pressure, has less tendency to swelling, smaller capillary pressures, and greater pore-water pressures than a similar sample of undisturbed soil. An internal migration of water from the disturbed to the undisturbed part of a sample may therefore take place.

On the other hand, strongly overconsolidated clays, whether remolded or undisturbed, have a tendency to swelling instead of consolidation during slow shear tests (939). This phenomenon is comparable to the volume increase of very dense sands during failure. Therefore, in samples of such soils an internal migration of water from the undisturbed to the partially disturbed sections may take place.

Gaseous or expansive soils.- As indicated in Section 5.9, a reduction of the total stresses and pore-water pressures will cause release and expansion of air and other gases entrapped in the pores of the soil or absorbed in the pore water. The pressure of the released gas is sufficient to cause displacement of the soil and formation of bubbles of considerable size, Fig. 105. In the vicinity of such bubbles the soil is partially disturbed and the pore-water pressure temporarily increased. However, it is possible that the attendant deformations of the sample as a whole may cause a decrease of the pore-water pressures in other parts of the sample, but it is an open question whether the development and expansion of gas bubbles ultimately will decrease or increase pore-water pressures and capillary forces. Taking both pore-water and gas pressures into consideration, it is probable that the effective stresses and the strength of the soil will be decreased, see Section 6.4.

Partially saturated soils.- A partially saturated soil in which the air forms isolated bubbles will act as the gaseous or expansive soils discussed above. When the saturation is so small that the air spaces are interconnected, so that air can enter or escape from the pores, the elastic expansion upon a reduction of the total stresses can take place practically unhindered, and the over-all capillary forces will be small and the effective stresses reduced. However, individual small elements or groups of grains will be under capillary pressure from menisci formed at interfaces between air and water in the interior of the sample. The unconfined compressive strength of the sample will probably be decreased, and the reduction depends not only on the character of the soil but also on the degree of saturation

Stress changes will probably have only a negligible effect on the results of other physical tests in which the soil is subjected to stresses equal to or exceeding those existing in the soil in situ

6.4 Change in Water Content and Void Ratio

A change in void ratio of a non-gaseous, fully saturated soil is accompanied by a corresponding change in water content, whereas the void ratio of gaseous soils may be changed without any change in water content, and the water content of partially saturated soils with interconnecting air spaces may be changed with only a minor change of the void ratio

Determination of volume changes.- Changes in volume and void ratio may occur both before, during, and after the actual sampling operation Volume changes before sampling are very difficult to determine, but they usually affect only the upper part of a sample taken through a bore hole. Volume changes after recovery of the sample can be determined by appropriate control tests, such as measurement of net length and/or weighing of the sample, although it is difficult to determine changes caused by internal migration of water It is unlikely that fully saturated soils of low permeability will be subject to significant volume changes during the actual sampling when the sampler is forced rapidly into the soil, but they may occur when the rate of advance is small, as in case of core boring and when a drive sampler is forced into the soil by slow jacking On the other hand, permeable and especially partially saturated soils may be subjected to appreciable volume changes during sampling

Specific recovery ratios will give some indication of the magnitude of the volume changes during sampling when these changes are small, but it must be borne in mind that the recovery ratios are influenced not only by volume changes but also by entrance of excess or displaced soil and by a downward deflection and stretching of the soil layers When the specific recovery ratio or, for samplers with thin walls or stationary piston, the total recovery ratio is equal to unity, it is probable that the soil has not been subjected to major volume changes However, the possibility that a compaction of the soil may be offset by entrance of excess soil and a swelling by a downward deflection and stretching of the soil layers must be taken into consideration

The best method of determining whether a given sampler or core barrel causes volume changes of certain types of soil is to compare the void ratio or density of the samples with that obtained in field density tests or, for samples taken in test pits, by advance trimming or block sampling methods.

Saturated cohesive soils.- An increase in water content and void ratio of a saturated, cohesive soil will increase the permeability and initial consolidation and decrease the shearing resistance, whereas a decrease in water content and void ratio will have the opposite effect. A moderate increase in water content is not as serious as a corresponding decrease, since the test results will be on the safe side

for practical applications, and since the sample can be restored to its original condition by allowing it to consolidate under stresses approximating those in the undisturbed ground On the other hand, a material decrease in water content may cause the test results to be on the unsafe side, and the effects of the decrease are to some extent irreversible This applies especially to preconsolidation pressures which may be increased by a decrease in water content

Saturated cohesionless soils.- The influence of a change in water content and void ratio of a saturated, cohesionless soil is similar to that described above for cohesive soils, but volume changes of cohesionless soils are generally very small unless a disturbance of the soil structure simultaneously occurs Samples of cohesionless soils are often remolded before testing and the test results expressed as a function of the void ratio, in which case the original volume changes will have no effect on the test results, but it is difficult to apply these results when the void ratio of the undisturbed deposit is not definitely known In particular, it is difficult to determine whether the void ratio is above or below critical values and thereby whether deformations will cause an increase or a decrease of pore-water pressures

Gaseous or expansive soils.- An increase in void ratio without a corresponding increase in water content, caused by release and expansion of gases entrapped in the soil or dissolved in the pore water, may seriously affect the results of consolidation tests and probably also the results of other physical tests.

Each load application in consolidation tests causes an initial increase in pore-water pressure and a decrease in volume of the gas bubbles This is followed by actual consolidation of the soil and probably also by a further decrease in gas volume, caused by plastic deformations of the soil and absorption of gas in the pore water. However, as the pore-water pressure decreases with the progress of the consolidation, there may be a re-expansion of the gas, but it is unlikely that the gas will attain its former volume since this would require entrance of gas into the capillaries or deformation of the soil, which now has increased strength

The reliability of the results of consolidation tests on gaseous soils depends to a large extent on the relative amounts of free gas or the degree of saturation of the soil in situ and that of the test specimen under comparable stress conditions. It is therefore important that the original volume and degree of saturation of the sample be determined as carefully as possible

Several methods of correcting the results of consolidation tests for the influence of gas in the soil have been suggested. The first and easiest of these methods consists in disregarding the sudden initial compression after each load application This method may yield coefficients of compressibility which are too small when the soil in situ contains free gas On the other hand, when the gas in the soil in situ is completely dissolved in the pore water, the coefficients of compressibility obtained by this method of correction may be too large, since the initial compression of the bubbles of free gas in the test specimen may be followed by an additional, gradual

decrease in volume on account of absorption of gas in the pore water, slow plastic deformations of the soil, and failure of the gas bubbles to expand to their original size towards the end of each load cycle

The second method, originally proposed by the late **D. E. Moran (342)**, requires a consolidation apparatus with a closed system which permits measurement of the amount of water actually forced out of or absorbed by the test specimen. In computing the pressure-void ratio curve, the volume changes of the test specimen as a whole are disregarded and only the changes in water content are considered The resulting diagram may furnish fairly reliable values of the coefficient of compressibility and the compression index when the gas in the soil in situ is completely absorbed in the pore water but too small values when the undisturbed soil contains free gas

A possible third method requires apparatus similar to that for the second method but with additional provisions for controlling pore-water pressures at the surfaces of the test specimen Before the actual test is started, the pore-water pressures and effective stresses in the soil should be increased to those existing in the soil in situ and maintained at these values for a considerable period of time in order to cause compression and re-absorption of the gases The pore-water pressure at the surface of the test specimen is maintained at the above mentioned value throughout the test, which otherwise is performed and evaluated as a standard test It is possible that this method will furnish more reliable results than the two mentioned above, but little is known about the time required for re-absorption of gases

Definite experimental data concerning the influence of an increase in void ratio, caused by formation and expansion of gas bubbles, on the strength of the soil are not available It is probable that the strength will be decreased, and it is in any case difficult to correlate the strength with the void ratios of the test specimen and the soil in situ The permeability expressed as a function of the total void ratio will probably be decreased, since water will flow around and not through the voids filled with gas

Partially saturated soils.- An increase in water content of a soil with interconnected, air-filled voids may destroy the apparent cohesion produced by the capillary menisci and forces at the boundaries of the air spaces, thereby decreasing the strength, and it may even cause disintegration or slaking of the soil A decrease in water content will increase the strength, but it may also produce cracking and, if the water content is decreased to the shrinkage limit, a change in the liquid and plastic limits of the soil

6.5 Disturbance of the Soil Structure

A disturbance of the soil structure may occur before, during, and after actual sampling In case of sampling through bore holes, the disturbance before sampling is usually confined to the upper part of the sample By use of proper methods and

equipment, the disturbance during sampling can generally be reduced to a very small amount for the central part of the sample, but the lower part may be disturbed in separating the sample from the subsoil, Section 6.9. In case of sampling in accessible explorations, the disturbance during sampling can usually be reduced to a negligible amount, but appreciable disturbance may occur before sampling and affect the entire sample, especially when the soil is soft and the sampling is performed in deep test pits or tunnels. Disturbance after sampling can to a large extent be avoided by proper care in sealing, shipment, and handling of the samples.

Determination of disturbance.- Excessive deformations generally indicate a disturbance of the soil structure. These deformations may appear as distortions or a change in thickness of the soil layers and as planes of failure. Changes in thickness are indicated by specific recovery ratios greater or smaller than unity. Distortions and planes of failure can often be seen on the surface of the sample, but they can be detected with much greater certainty by slicing the sample and partial drying and trimming of the sliced sections. The sensitivity to deformations differs greatly for the various types of soils. Some plastic soils can withstand a strain of several percent without an appreciable change in physical properties, whereas a strain of less than one percent may cause serious disturbance of brittle soils.

The soil structure may be disturbed and the physical properties changed even when there is no change in thickness or visible distortions or planes of failure. Such disturbances without outward manifestations are, of course, difficult to detect. Control tests performed in the field and later repeated in the laboratory will disclose the change in physical properties after sampling, but such changes may be caused not only by disturbance of the soil structure but also by a change in water content and void ratio and by chemical changes. As will be explained in the following paragraphs, the test results will often give some indication of the condition of the sample.

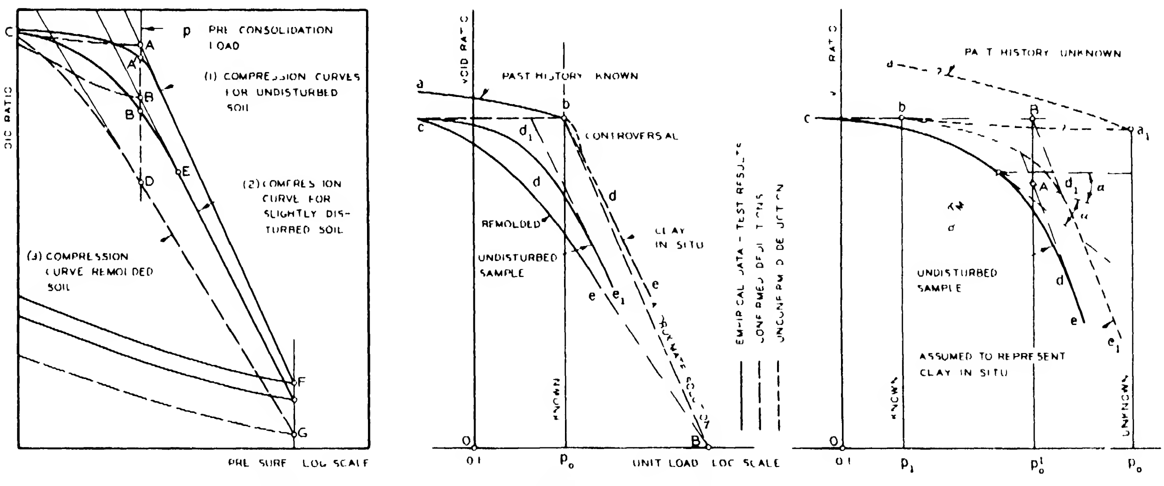
Nature of disturbance.- A disturbance of the soil structure may consist of a weakening of the bond between particles or a rearrangement of the structural pattern formed by the soil grains. A weakening of the bond between colloidal particles of clay minerals and organic matter is often thixotropic in character, that is, the bond may in part be reestablished after the source of disturbance ceases to act. The disturbance may in such cases be explained roughly as a temporary liberation of bound water molecules in the film of partially solidified water surrounding the colloidal clay minerals.

A rearrangement of the structural pattern formed by the soil grains is generally accompanied by a tendency to a change in void ratio and by a change in pore-water pressures and of capillary pressures at the surface of a sample exposed to air. The void ratio of a loose cohesionless soil or a cohesive soil in a state of normal consolidation or slight overconsolidation tends to become smaller by disturbance, and the pore-water pressure will consequently be increased until the change in void ratio has been effected. On the other hand, the void ratio of a dense cohesionless soil or a strongly overconsolidated clay tends to increase and the pore-water pressure

to decrease by a disturbance of the soil structure The following comments on the effects of these disturbances are primarily confined to the results of laboratory tests on saturated, cohesive soils

Influence on consolidation tests.- A disturbance of the soil structure will generally cause a tendency to additional consolidation of the soil or a downward displacement of the pressure-void ratio curve, Fig 138 The transition between the initial recompression and the straight or virgin parts of the diagram will be rounded off and the stress history and preconsolidation pressure thereby obscured The slope of the virgin compression curve in the usual semi-logarithmic plot will be decreased slightly, and the curve for a partially disturbed soil will join that of the undisturbed soil at a certain high pressure and at least at zero void ratio. Corrections of the pressure-void ratio curve, as determined in the laboratory, to obtain that for the undisturbed soil have been discussed in many papers The following brief review of such corrections is primarily based on the paper by **Rutledge (963)** and the discussion of this paper by **K. Terzaghi.**

When the soil is in a state of normal consolidation and the preconsolidation load, p_o in Fig 138B, is known, the virgin compression curve for the soil in situ may be determined with reasonable accuracy by drawing a line through point b, parallel with or intersecting the virgin curve for the partially disturbed soil at zero void ratio However, the transition between the initial recompression and the virgin



A - EFFECT OF DISTURBANCE
P C RUTLEDGE p 1165

B - NORMAL CONSOLIDATION
K TERZAGHI p 1199

C - OVERCONSOLIDATION
TRANS AM SOC C E VOL 109 1944

FIG 138 - SAMPLE DISTURBANCE AND CONSOLIDATION TESTS

parts of the curve and the settlement of structures which produce only a slight increase in pressure cannot be determined with certainty On the other hand, when the structure produces a large increase in pressure, the settlements computed on the basis of the corrected pressure-void ratio curve usually agree satisfactorily with observed settlements

When the soil is overconsolidated, the preconsolidation pressure may be determined by comparison with the rebound or recompression curves, Fig. 138A, or by means of the construction suggested by **A. Casagrande**, Fig 138C The virgin compression curve for the soil in situ may then be determined by drawing a line through point A in Fig 138A or point B in Fig 138C parallel with or slightly steeper than the virgin compression curve for the partially disturbed soil However, the determination of the preconsolidation pressure may be considerably in error when the soil has been subjected to serious disturbance, and the shape of the transition between the recompression and virgin parts of the diagram is still more uncertain than for a normally consolidated soil

In general, a straight or slightly concave virgin compression curve and a fairly sharp transition between this curve and the initial recompression curve with a good definition of the preconsolidation pressure will usually indicate that the sample has not been subjected to appreciable disturbance However, it must be borne in mind that some undisturbed soils have a convex compression curve and that the virgin compression curve for other soils is slightly concave even when the soil is remolded

In addition to consolidation tests on undisturbed samples, it may in many cases be advantageous to perform such tests also on remolded samples The compression curves for the remolded samples indicate the trend of the influence of increasing structural disturbance and may thereby assist the extrapolation required to estimate the compression curves for the soil in situ as well as give some indication of the degree of disturbance of the undisturbed samples

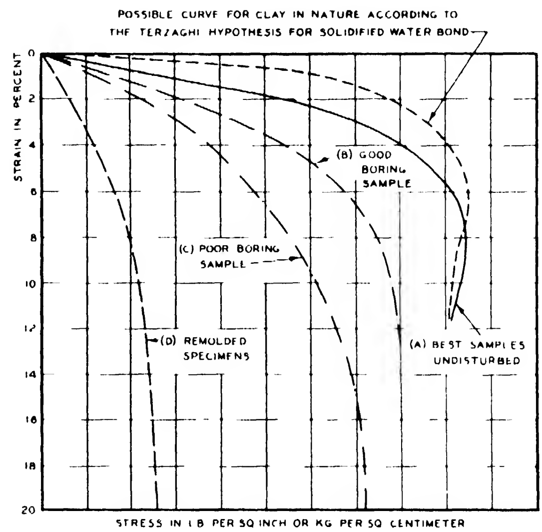
Influence on unconfined compression tests.- A disturbance of the soil structure will generally cause a decrease of the unconfined compressive strength and of the nominal modulus of elasticity as shown in Fig 139A The ratio between the compressive strength of the remolded soil and that of the undisturbed soil, or the corresponding ratio between the moduli of elasticity, indicates the sensitivity of the soil to structural disturbance A few such ratios are given in the table in Fig 139A, and it will be observed that the deformations are much more sensitive to structural disturbance than the ultimate strength The influence of the disturbance varies between much greater limits than indicated in this table Some stiff soils may be transferred into a semi-liquid state whereas other soils lose only very little and a few may even gain slightly in strength by remolding, **Faber (920), Tschebotarioff (975).**

A loss in strength by remolding is probably caused by a weakening of the bond between the soil particles and by a tendency of the void ratio to decrease. This tendency will cause an increase in pore-water pressure and consequently a decrease in capillary pressure and of the internal, effective, normal stresses between the soil grains. An increase in strength by remolding is usually attributed to a secondary structure of the soil and to the elimination of weak joints and slickensides by the remolding This explanation is undoubtedly correct for some of the soils exhibiting this rather unusual property, but it is possible that some of these soils are

so strongly overconsolidated that the disturbance tends to produce expansion with a consequent decrease in pore-water pressure and increase of the capillary pressure and internal, effective stresses

The decrease in strength of good undisturbed samples, on account of unavoidable structural disturbance, is in many cases only moderate Moreover, a moderate decrease in strength does not seriously interfere with the practical application of the test results, since it is compensated for by neglecting the influence of progressive failure and the consequent disturbance of the soil and decrease of the average shearing resistance along the assumed surface of failure On the other hand, the influence of a slight structural disturbance on the nominal modulus of elasticity is much more pronounced, and there are no compensating factors in the application of the test results Hence, the observed initial settlements of structures are usually much smaller than those computed on the basis of moduli of elasticity determined by laboratory tests on undisturbed samples

In addition to the unconfined compression tests on undisturbed samples, it is advisable always to make a few tests on specimens of the remolded soil in order to obtain an indication of the sensitivity of the soil to structural disturbance When the stress-strain curve for the undisturbed sample is straight until the stress reaches 30 to 50 percent of the compressive strength, it will usually indicate that the sample is not seriously disturbed, whereas a stress-strain curve which is curved from the start and which falls close to the curve for remolded soil usually indicates serious structural disturbance However, it must be taken into consideration that some soils have a fairly straight stress-strain curve even in a remolded state and that other soils do not lose appreciably in strength by structural disturbance



DISTURBANCE AND STRESS-STRAIN CURVES

SOURCE OF MATERIAL		TYPE OF CLAY	COMPRESSIVE STRENGTH KG PER SQ CM			MODULI OF ELASTICITY KG PER SQ CM		
			UNDISTURBED	REMOLDED	RATIO REMOLD / UNDIST	UNDISTURBED	REMOLDED	RATIO REMOLD / UNDIST
CHICAGO		GLACIAL	0 50	0 12	0 24	24	0 8	0 03
CHICAGO	3	GLACIAL	0 94	0 30	0 32	28	5 7	0 20
CHICAGO	3	GLACIAL	2 20	0 76	0 34	130	8 0	0 06
CHICAGO	3	GLACIAL	4 10	2 10	0 51	295	4 4	0 15
BOSTON	1	MARINE	2 30	0 30	0 13	102	18	0 18
LAURENTIAN	1	MARINE	6 10	0 40	0 07	740	28	0 04
MEXICO CITY	3	VOLCANIC	0 96	0 18	0 19	45	3 5	0 08

TESTS BY (1) A CASAGRANDE (2) R B PECK (3) P C RUTLEDGE

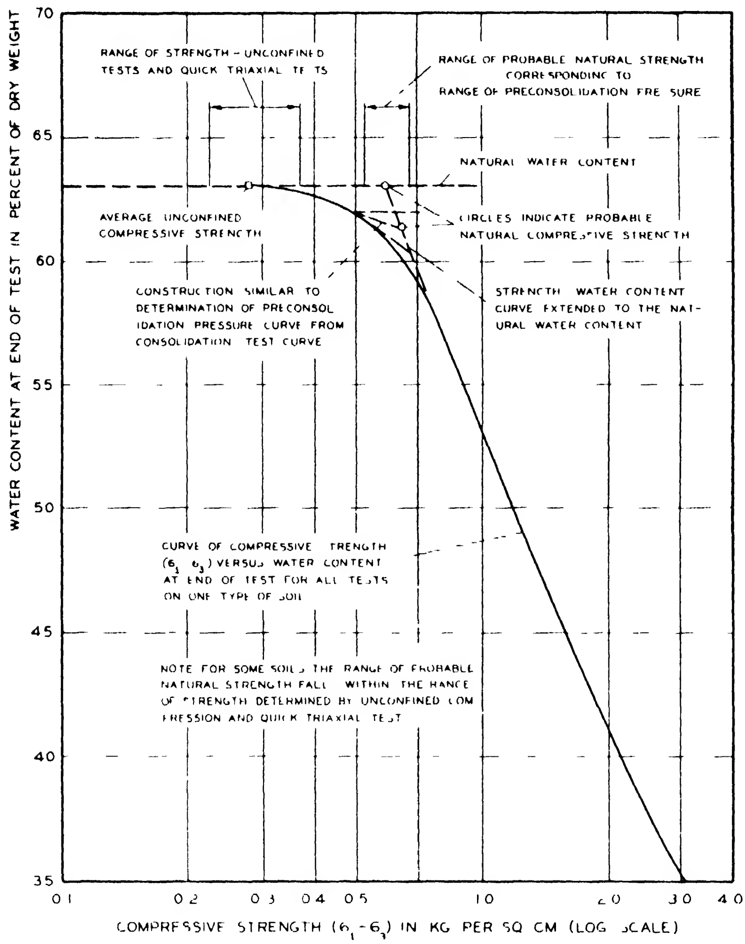
INFLUENCE OF COMPLETE REMOLDING

P C RUTLEDGE TRANS AM SOC C E VOL 109 1944

FIG 139-A - SAMPLE DISTURBANCE AND UNCONFINED COMPRESSION TESTS

Influence on direct shear and triaxial tests.- The foregoing comments on the influence of a disturbance of the soil structure on the results of unconfined compression tests apply in principle also to the results of direct shear tests and triaxial

compression tests and especially to those of unconsolidated quick tests. However, in case of consolidated quick and slow tests, the decrease in void ratio during the initial consolidation and during the test itself will be increased by an initial disturbance of the soil structure, as indicated in the discussion of consolidation tests. This additional decrease in void ratio will cause an increase in strength which will counteract and may even exceed the decrease in strength caused by the initial structural disturbance and weakening of the bond between the particles Therefore, for some soils and certain stress conditions, a disturbance of the soil structure may cause the results of consolidated quick and slow tests to be on the unsafe side for practical applications



METHODS OF ESTIMATING NATURAL STRENGTH OF CLAYS FROM TESTS ON UNDISTURBED SAMPLES

REPORT ON TRIAXIAL SHEAR RESEARCH CORPS OF ENGINEERS VICKSBURG APRIL 1947

SAMPLE DISTURBANCE AND TRIAXIAL COMPRESSION TESTS

FIG 139-B

When the strength of the soil is expressed as a function of the void ratio instead of the principal stresses, Fig 139B, the effect of the additional decrease in void ratio is automatically taken into consideration, and it is even possible that the effect of a small initial structural disturbance will be reduced to a negligible amount when the sample is consolidated under pressures in excess of the preconsolidation pressure. The strength-void ratio diagram is similar to the pressure-void ratio curve obtained by consolidation tests As suggested by **Casagrande and Rutledge** (116) and shown in Fig 139B, the approximate strength of the soil in situ may then be determined by extrapolation to the natural void ratio of the soil or by means of a construction similar to that used for determination of the preconsolidation pressure.

During the Cooperative Triaxial Shear Research (116) the natural strength

of several soils was determined in the above mentioned manner, and it was found that this strength is considerably larger than the strength obtained by unconfined compression or quick triaxial tests when the soil is brittle and very sensitive to structural disturbance; whereas it falls within the range of strengths obtained by these two tests when the soil is plastic and relatively insensitive to structural disturbance. These conclusions are not final, and further research on the effect of unavoidable disturbance of samples on the results of laboratory tests is needed

Influence on permeability tests.- When a disturbance of the soil structure causes a change of the void ratio, the permeability will also be changed However, it is possible that a disturbance of the soil structure may cause a change in permeability even when the void ratio is not changed, that is, the disturbance may affect the permeability-void ratio curve. **Terzaghi and Peck (246)** cite several examples of remolding causing a very large decrease in permeability of various silty, organic, and calcareous clays An increase in permeability of highly colloidal and bentonitic clays on account of remolding has been reported. It is possible that such an increase in permeability is only temporary or a thixotropic phenomenon, that is, some of the water molecules in the film of partially solidified water are temporarily liberated and the effective percolation channels thereby enlarged

A disturbance of the structure of stratified soils consisting of alternating laminae of pervious and relatively impermeable soils, may cause a decrease in permeability parallel to and an increase perpendicular to the stratifications In case of anisotropic soils, like loess, in which the vertical permeability is much greater than the horizontal permeability, the former may be decreased by disturbance of the soil structure.

Further research on the influence of structural disturbance on the permeability of a soil is needed, especially in connection with estimates of the time rate of consolidation and settlements of structures Estimated rates of settlement, based on results of laboratory tests, are usually much smaller than observed rates of settlement of the completed structures. This difference is generally attributed to the presence of intermediate, thin laminae of permeable soil in the compressible deposit This explanation is undoubtedly correct in many cases, but a decrease in permeability of the samples, on account of a disturbance of the soil structure during sampling, would also cause the estimated rate of settlement to be smaller than the actual rate.

6.6 Chemical Changes

The soil close to the bottom of the bore hole may be affected by salts in the wash water or the ingredients of the drilling fluid, but the penetration is generally slight except in pervious soils. Oxidation may occur by prolonged exposure of the soil to air in accessible explorations or during the preparation of test specimens. However, the greatest danger of chemical changes exists when soil samples are stored in untreated steel containers for protracted periods. Contact with copper, brass, zinc, etc., may in special cases also cause chemical changes in the soil.

The danger of chemical changes is aggravated by the presence of acids or bases in the soil or pore water and by electrical currents which may be generated when metals of different kinds are in contact with the soil. Air and moisture filled voids between the sample and the container will also promote chemical changes as well as growth of fungus Containers should preferably be coated with lacquer; at least, the sealing caps or disks should be of electrically inert materials or of the same kind of metal as the container in order to avoid electrolytic action This requirement should also be observed in the design of testing equipment in which the test specimen will be in contact with metals for periods exceeding a few hours

Determination of disturbance.- Organic soils are often subject to color changes by oxidation Contact with metals and especially steel may cause conspicuous discolorations, a hardening and pitting of the soil, and in other cases a strong adhesion between sample and container However, chemical changes may take place without conspicuous outward manifestations Minor changes in the consistency of the soil can be detected by means of the usual control tests, but changes in consistency do not necessarily indicate chemical changes Control tests in the form of chemical analyses are seldom made as a part of soil sampling operations for civil engineering purposes, and correlations between chemical and physical changes must also be established before the results of chemical control tests can be properly evaluated

Nature and effect of chemical changes.- Whereas the effects of chemical changes of the soil have been studied extensively in investigations for agricultural and industrial purposes, very few data are available concerning the chemical changes which may occur during sampling, storage, and testing of soils, or the effect of such changes on those physical properties which are of primary interest to the civil engineer

In soils consisting primarily of quartz and similar relatively inactive minerals, the chemical changes which may occur during sampling and storage consist mainly of deposition of chemical compounds in the voids and the formation of a bond between the soil grains In soils containing clay minerals the principal change is a base exchange or an exchange of cations at the surface or corners of the crystal lattice of the minerals with ions in the pore water The corresponding changes in physical properties depend, of course, on the type of ions which have been **exchanged**; for example, an exchange of sodium ions with calcium ions and especially with hydrogen, iron, or aluminum ions will cause a decrease in Atterberg limits and compressibility and an increase in shearing resistance of the soil, **Endell and Hoffmann (919).** Organic compounds in the soil may be subject to both oxidation and base exchange.

Base exchanges are facilitated by the passage of an electric current which through electrolysis of water and metals makes the hydrogen and other ions available for exchange. It is also possible that such a current may cause partial cementation through formation of various aluminates which are deposited in the voids. In

general, it is probable that chemical changes which are caused by contact between the soil and metal containers or testing equipment and by electrolysis will produce a decrease in compressibility and an increase in shearing resistance of the soil and will thereby cause the results of laboratory tests to be on the unsafe side for practical use.

6.7 Mixing and Segregation of Soil Constituents

Mixing of soil from adjacent strata often occurs in samples obtained with augers, bailers, sandpumps, and slit or cup samplers Mixing and segregation of the soil constituents in samples taken with drive samplers and core barrels are generally caused by improper cleaning or use of an open sampler in an uncased bore hole but may also be due to piping and partial liquefaction, caused by creation of a vacuum over the sample

Mixing of the soil strata will cause distortions which are readily discernible by slicing and partial drying of the samples, but it may occasionally be difficult to determine whether the distortions do not exist in the undisturbed deposit However, mixing of soil layers during boring, cleaning, and sampling operations primarily affects the upper part of the sample and is generally accompanied by a conspicuous softening of the soil

When only soil layers in close proximity have been mixed, the sample as a whole may be considered as representative of the average condition and used for approximate identification and for tests to determine the suitability of the soil for construction purposes, but the samples are unsuitable for laboratory tests when some of the soil constituents have been removed or replaced with soil from distant strata or with foreign matter

6.8 Requirements for Undisturbed Samples

Since a reduction of the total stresses acting on the soil in the undisturbed deposit cannot be avoided during the sampling operation and the preparation of laboratory test specimens, a truly undisturbed sample cannot be obtained, but the sample may nevertheless be suitable for all laboratory tests and for practical purposes considered as undisturbed when the following basic requirements are satisfied

1 No disturbance of the soil structure
2 No change in water content or void ratio
3 No change in constituents or chemical composition

It is very difficult to determine whether, for a given sample, these requirements are fully satisfied, and even when they are complied with, possible effects of the unavoidable stress changes should be realized and taken into consideration in planning the tests and evaluating the results. Referring to the methods of detecting disturbances, discussed in the foregoing sections, the strict requirements for

undisturbed samples may be replaced in part by the following modified or practical requirements

A The specific recovery ratio shall not be greater than 1 00 nor smaller than $(1 - 2C_1)$, where C_1 is the inside clearance ratio at the cutting edge When thin-wall drive samplers, samplers with stationary piston, or core barrels are used, it is generally sufficient that the total recovery ratio be equal to or slightly smaller than unity

B On the surface of or in sliced sections of the sample there must be no visible distortions, planes of failure, pitting, discoloration, or other signs of disturbance which can be attributed to the sampling operation or handling of the sample

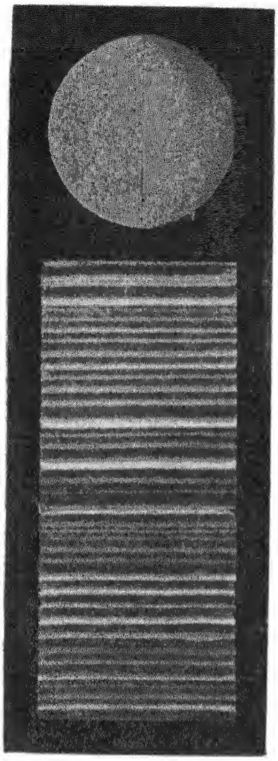
C. The net length and weight of the sample and the results of other control tests must not change during shipment, storage, and handling of the sample.

It is strongly emphasized that these requirements are complementary. There may be no visible distortions of the soil layers even when the specific recovery ratio is considerably above or below unity, Fig 141, and the soil layers may be seriously distorted even though the recovery ratio is equal to unity, Fig 142 On the other hand, it must be borne in mind that both distortions and planes of failure often exist in the undisturbed deposit When irregular distortions in the sample are found below or between undistorted strata, Fig 143, they are likely to be natural distortions. On account of the direction of displacement or the attendant distortions of the planes of failure shown in Fig 144A and B, it is probable that they are natural planes of failure, but the possibility that they may have been caused by the sampling operation cannot be excluded

6.9 Disturbance of Undisturbed Samples

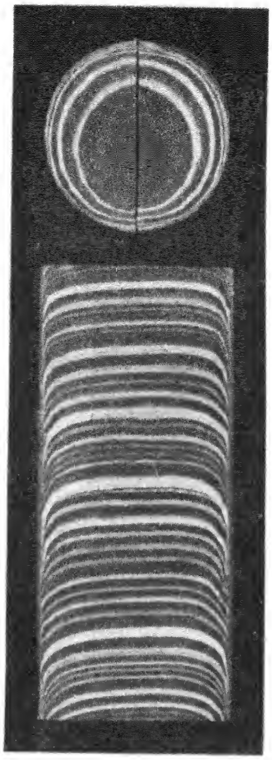
The modified practical requirements for undisturbed samples, suggested in the foregoing section, are not fully equivalent to the basic requirements, and the samples may have been subjected to a change in physical properties when the modified requirements are satisfied For example, a compaction or decrease in void ratio may be offset by entrance of excess soil, and a slight downward deflection and stretching of the soil before it enters the sampler may be offset by gaseous swelling and distortion in the opposite direction by action of the inside friction. First of all, the modified requirements must be satisfied, and further indications of the condition of the sample and the reliability of the results of laboratory tests may be obtained by the following observations and comparative tests.

Shape of stress-strain curves.- As mentioned in the foregoing sections, the pressure-void ratio or stress-strain diagrams obtained in consolidation tests and in unconfined and triaxial compression tests will often indicate disturbance of the sample when:



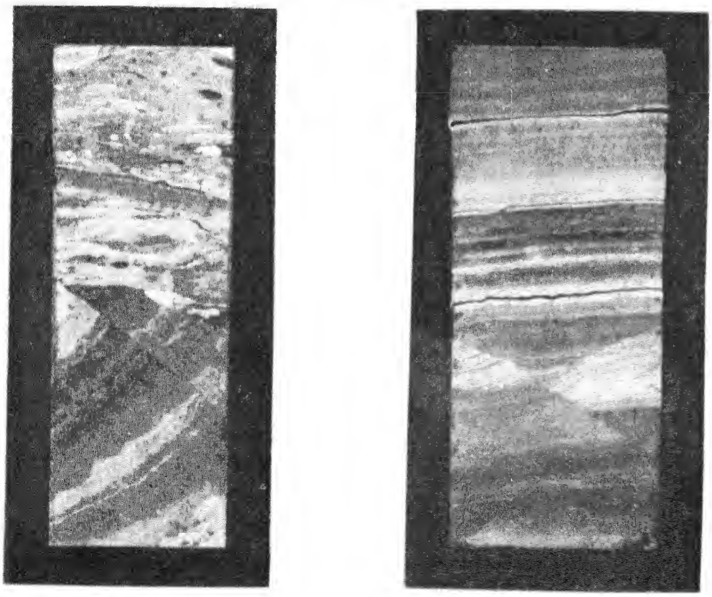
SOFT VARVED CLAY - DEPTH 3 FT
4¾" MOHR SAMPLER - FAST PUSHING
SPEC. RECOVERY OF SECTION = 110 %

EXCESS RECOVERY
WITHOUT DISTORTIONS
FIG 141



SOFT VARVED CLAY - DEPTH 5 FT.
4¾" MOHR SAMPLER - HAMMERING
SPEC. RECOVERY OF SECTION = 100 %

SERIOUS DISTORTIONS
WITH FULL RECOVERY
FIG. 142



MED. SOFT SILTY CLAY - DEPTH 54' - SHELBY
TUBING - PUSHING - D = 2", H = 54", L = 54"

MED. STIFF SILTY CLAY - DEPTH 85' - SHELBY
TUBING - PUSHING - D = 3", H = 60", L = 53"

POSSIBLE NATURAL SHEAR FAILURES IN UNDISTURBED SAMPLES
FIG. 144

MEDIUM SOFT SILTY CLAY - DEPTH 50 FT
2" SHELBY TUBING - FAST PUSHING -
PENETRATION 54" - SAMPLE LENGTH 54"

UNDISTURBED SAMPLE
WITH NATURAL DISTORTIONS
FIG. 143

(1) The preconsolidation load is poorly defined and the entire consolidation curve has a convex curvature in the usual semi-logarithmic plot

(2) The stress-strain curve for compression tests is curved from the start and the maximum stress and corresponding strain are poorly defined.

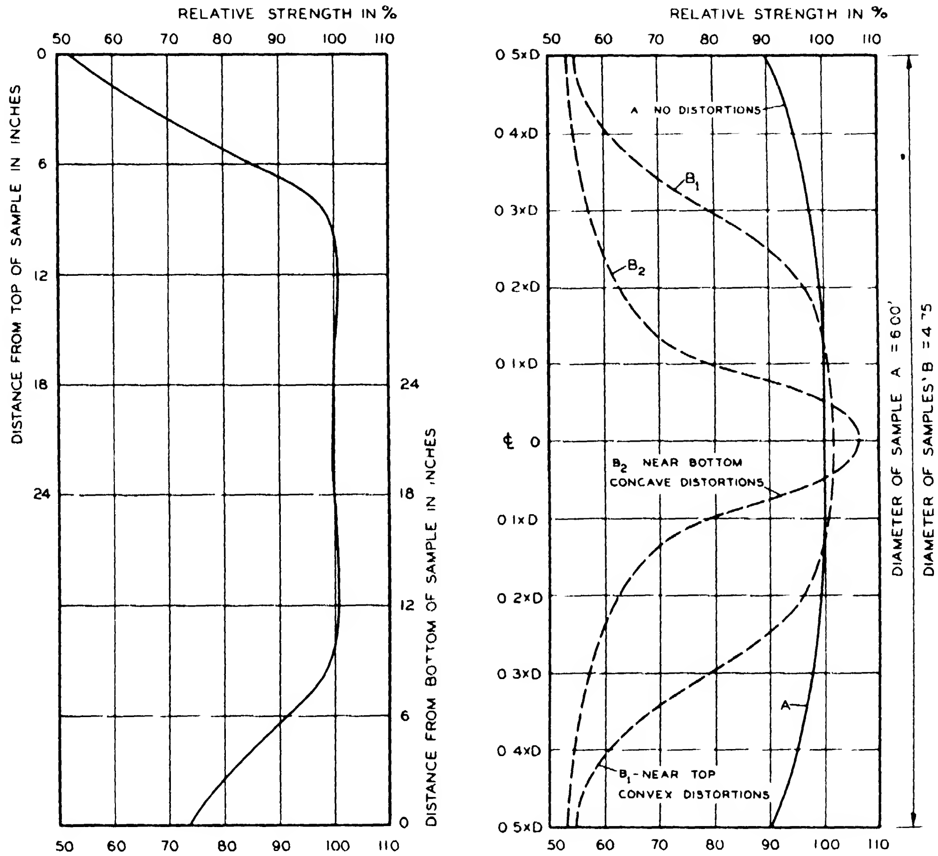
However, it must also be borne in mind that the consolidation and stress-strain curves of some soils are curved even when the material actually is undisturbed, whereas these curves are fairly straight for other soils even when these soils are remolded To determine the influence of structural disturbances on the shape of the curves and to obtain an indication of the degree of disturbance of undisturbed samples, it is advisable to repeat a few of the tests, at least some unconfined compression tests, with remolded soil

Variations of disturbance within a sample.- Even when the modified requirements for undisturbed samples are satisfied, the soil will generally be partially disturbed for some distance from both the top, bottom, and the cylindrical surface of the sample A few tests to determine variations in the unconfined compressive strength over the length and diameter of samples were made during the research.

Variations in strength over the length of samples were determined by cutting test specimens, 5/8 in in diameter and 1-1/4 in long, at 3-in to 6-in intervals at the center of samples of silty clay taken with a 2-in. thin-wall piston sampler. The unconfined compressive strengths were determined by means of the apparatus shown in Fig 357, and the relative strengths were expressed as a percentage of the average strength of the test specimens taken more than 9 in from the top and bottom of the samples The results of tests on 11 samples of fairly uniform soil were averaged and are presented in Fig 140A It will be seen that the 2-in samples are partially disturbed for a distance of about 8 in from the top and bottom of the samples The decrease in strength in the upper part of the sample is due to disturbance of soil near the bottom of the bore hole before actual sampling is started, whereas the decrease in the lower part is caused by transmission of tensile and torsional forces to separate the sample from the subsoil and by swelling on account of contact with free water and/or internal migration of water to the partially disturbed section

Variations in strength over the diameter of 4-3/4-in and 6-in. samples were determined in a similar manner A 2-cm thick circular slice was first cut from a sample by means of a thin wire saw, and a 1-cm wide strip was then cut from the center of this slice and divided into 1-cm square test specimens. The variations in the unconfined compressive strength, expressed as a percentage of the average strength of the three test specimens closest to the center of the sample, are indicated in Fig 140B. Only a few pilot tests of this type were made and the results were to some extent influenced by variations in the character of the soil Therefore, the curves shown in Fig 140B indicate only a probable trend, and it is highly desirable that more accurate and detailed tests be made to determine variations in strength and disturbance over the diameter of samples.

Curves indicating relative values of the modulus of elasticity over the length or diameter of samples will probably show considerably greater variations than



UNCONFINED COMPRESSION TESTS ON 5/8 ø TEST SPECIMENS FROM 11 SAMPLES OF BOSTON BLUE CLAY TAKEN WITH A THIN-WALL PISTON SAMPLER SAMPLE DIAMETER = 1 90 LENGTH = 36 TO 42, RECOVERY = 100 %, AVERAGE STRENGTH OF SECTIONS MORE THAN 9 FROM ENDS = 1 23 kg/cm² = 100 %

A - RELATIVE STRENGTH OVER LENGTH

UNCONFINED COMPRESSION TESTS ON 1 cm D TEST SPECIMENS
CURVE A 6 SAMPLE OF SILTY CLAY MISSOURI SAMPLER ADVANCE TRIMMING, RECOVERY 100 % NO DISTORTIONS
CURVES B 4 3/4 SAMPLES OF SILTY CLAY, MOHR SAMPLER SLOW JACKING, TOTAL RECOVERY 100 %, LARGE DISTORTIONS

B - RELATIVE STRENGTH OVER DIAMETER

VARIATIONS OF COMPRESSIVE STRENGTH IN SAMPLES

FIG 140

those for the maximum compressive strength and would therefore be better indicators of disturbance, but they are also more difficult and time-consuming to determine with the required accuracy.

Comparison of samples taken by various methods.- The disturbance during the actual sampling operation is to a large extent eliminated when the samples are taken in accessible explorations by advance trimming or block sampling methods. A comparison of the results of tests on such samples and those obtained in bore holes by means of drive samplers or core barrels will then indicate the disturbance

of the latter, provided the soil in the accessible exploration has not been disturbed before sampling.

Results of some comparative tests of this type are cited by **Peck (541) and Rutledge (963),** who found that samples obtained with simple 2-in. open drive samplers suffered an appreciable decrease in strength during sampling, whereas **Dawson** (discussion of 963) found little difference in the physical properties of samples obtained with a 5-in. thin-wall drive sampler and block samples taken in test pits.

Whenever there is an opportunity to do so, it is advisable to make such comparative tests, and especially when it is attempted to expedite the work by use of simplified samplers and methods, as in control sampling of earth structures. Comparative tests should also be made when new types of samplers are first tried out, during sampling operations in virgin territory, or when new types of soils are encountered. However, it must also be borne in mind that the soil around a test pit or other accessible explorations under certain conditions may be seriously disturbed before sampling. It is possible that samples obtained with a properly designed thin-wall piston sampler through a bore hole filled with water or drilling fluid in some cases may be less disturbed than samples obtained in a test pit or accessible boring to the same strata.

Comparison of samples of various diameters.- When soil conditions are such that there is danger of disturbance of the soil around accessible explorations, or when the depth to the strata under investigation is too great, it may be possible to obtain an estimate of the influence of the disturbance during the sampling operation by comparison of the results of tests on specimens cut from the center of samples taken in bore holes with samplers of various diameters.

There can be little doubt that the disturbance of the soil during the sampling operation decreases with increasing diameter. When the results of tests on samples of various diameters are plotted as a function of the diameter, the resulting diagrams will often approach, asymptotically with increasing diameter, certain maximum or minimum values of the physical constants and coefficients. These values will then represent the physical properties of samples which have been subjected to no other disturbance during the sampling operation than that caused by the unavoidable change in stress conditions.

Comparison of predicted and actual behavior of structures.- As evidence of the undisturbed condition of samples, it is occasionally stated that the actual amount of settlement or the position of a surface of sliding is in close agreement with that predicted on the basis of tests on the samples. However, such an agreement does not furnish conclusive proof of the undisturbed condition of the samples, since errors resulting from disturbance of the samples may be offset by other errors caused by the method of testing or by approximations and assumptions in the application of the test results. For example, the unconfined compressive strength of slightly disturbed samples often agrees fairly well with the computed average shearing resistance

along a surface of failure, since the effect of progressive failure and the consequent decrease of the average shearing resistance generally are neglected in these computations.

The agreement between the predicted and actual behavior of a foundation or earth structure only indicates that the combination of particular methods of sampling, testing, and application of the test results furnishes reasonable results for a specific type of structure or problem and specific soil conditions, but it does not furnish conclusive proof of the absence of sources of error in any one of the three interdependent phases of the investigation

6.10 Future Research

The research on undisturbed sampling of soils may be divided into the following three phases (A) general survey of the requirements and of the currently used methods of subsurface exploration and sampling of soils, (B) investigation of the causes of disturbance of soil samples and development of methods and equipment for obtaining samples which satisfy the modified or practical requirements for undisturbed samples, discussed in Section 6 8, and (C) comparative tests to determine the extent and degree of disturbance in samples which comply with the practical requirements, and development of methods for estimating the properties of the soil in situ from the results of tests on such samples

The research completed to date has mainly been confined to the first two of the above mentioned phases, and problems on which additional research is needed have been mentioned from time to time in the foregoing chapters A brief outline of desirable future research is given in the following paragraphs

(A) **General survey.-** The collection of data and critical review of new developments in the subsurface exploration and sampling of soil and rock should be continued

(B1) **Drive samplers.-** The principal causes and types of disturbance of the soil during drive sampling have been determined and approximate criteria for the design and operation of drive samplers established during the research, but further systematic experiments with the following objects are needed

(1) Closer investigation of the causes of convex distortions in samples, to enable a more accurate determination of when such distortions are caused by caving of the bottom of the bore hole, improper cleaning before sampling, entrance of excess soil, or by inside wall friction.

(2) Closer investigation of the origin and causes of shear failures in samples, to permit determination of when they occur before or after the soil enters the sampler, when they are produced by displacement of soil by the cutting edge or by the inside friction and overdriving, and when they are not caused by the boring and sampling operations but represent zones of failure of the soil in situ

(3) Closer determination of the allowable values of the area ratio and of the influence of the shape and taper of the cutting edge and of a stationary piston on these values

(4) Closer determination of the optimum values of the inside and outside clearance ratios, and of the influence of these ratios and of the speed of penetration on the length and disturbance of samples of the principal types of soils.

These experiments can be performed in essentially the same manner as those of the completed research, that is, by determination of recovery ratios, examination of sliced samples for signs of disturbance, and by performance of simple control tests Possible mechanical improvements of the samplers and operating equipment and of methods for preventing loss of the samples are not mentioned in this outline, since such improvements can and probably will be made during practical sampling operations

(B2) **Core barrels.-** Whereas extensive practical research has been conducted to determine the requirements for the design and operation of core barrels for use in rock, very few data are available on systematic experiments to determine these requirements for core barrels for use in soils Time and circumstances did not permit such experiments to be performed during the research covered by this report

Some of the results obtained for drive samplers can also be applied to core barrels, but systematic experiments are required for solution of special problems. The first part of this research may follow the same plan as the research on drive samplers, and the investigation of the condition of the samples obtained may at first be confined to determination of the recovery ratios and examination of sliced samples for indications of disturbance In most cases it will be sufficient to determine the total recovery ratios, but it is desirable that specific recovery ratios be determined in some of the experiments. The principal objects of the research may be summarized as follows

(1) Determination of the principal types of disturbance and their causes, with special attention being given to disturbances by transmission of torsion to the subsoil and to the sample, to the influence of whip and vibrations, and to erosion and contamination of the soil by wash water and drilling fluid

(2) Determination of the optimum number, shape, size, clearances, and arrangement of the teeth in the coring bit and of the shape and position of the cutting edge of the inner barrel.

(3) Determination of the influence of the method of operation, that is, the bit speed, feed pressure and rate, and the pump pressure and discharge

(4) Determination of the types of soils of which undisturbed samples may or should be obtained by core boring instead of drive sampling.

Research on these problems should be made by systematic experiments under closely controlled conditions Possible mechanical improvements of swivel joints, vents and check valves, core catchers, and a core barrel plug or piston can be made during practical coring operations.

(B3) Preservation of samples.- A few experiments with lacquering of sampling tubes and liners and with various methods of preserving samples during shipment and storage have been made, but the results are not conclusive and additional experiments with the following objects are needed

(1) Determination of the best type of lacquer, enamel, or electroplating of liners and thin-wall sampling tubes to obtain minimum inside friction, maximum toughness and hardness, and maximum protection against corrosion of the tubing and chemical changes of the soil during protracted storage of samples

(2) Development of better methods for preservation of large samples by investigating the effect of various admixtures to and various blends of paraffins and waxes in which the samples are encased, or by spray-coating the samples with modern rubber and plastic sealing compounds

(C) Comparative tests.- Since the object of these tests is to determine the extent and degree of disturbance by comparison of the results of tests on various test specimens, it is essential that the experiments be performed in uniform soils. It is desirable that comparative tests of the following categories be performed

(1) Determination of variations in strength and elasticity over the length and diameter of samples A few tests of this type were made during the research and are described in Section 6.9, but many more are needed

(2) Comparison of void ratios, water contents, or dry densities of samples of various diameters or obtained by various methods in an effort to determine the volume changes of relatively pervious or partially saturated soils during sampling

(3) Comparison of the consolidation, permeability, and strength characteristics of test specimens cut from samples of various diameters or obtained by various methods with the object of determining the change in these physical properties during sampling A further object is to develop methods of correction or extrapolation of the results of tests on practical undisturbed samples, so as to obtain reliable estimates of the physical properties of the soil in situ This last mentioned object is between the scope of the research described in this report and that of research on soil testing.

As previously mentioned, a considerable amount of data on the results of comparative tests and on methods of correcting the results of tests on slightly disturbed samples is contained in the paper by **P. C. Rutledge (963)** and in the discussions of this paper

Location of uniform soil deposits.- The majority of soil deposits are far

from uniform, and variations in physical properties, at least in a vertical direction, are as a rule to be expected Much time and effort was lost during the research on soil sampling, and it was in many cases impossible to formulate definite conclusions on account of such variations in the physical properties of the soils in which the experiments were made

A great variety of varved sands, silts, and clays are found in the Connecticut Valley and other places in the glaciated regions of the Northern Hemisphere These deposits are excellently suited for experiments to determine whether a given sampler or sampling method causes deformation of the soil, but the difference in the properties of the alternating laminae is generally so great that these deposits cannot be used for a closer determination of the extent and degree of disturbance by a comparison of the physical properties of various test specimens or samples

Very uniform soil deposits or strata are a prerequisite for the comparative tests required in the third and final phase of the research on soil sampling Soil deposits which are easily accessible and sufficiently uniform for the above mentioned purpose are very rare, but an organized search for such deposits of the principal types of soils would be well worth the effort If they could be located, it would benefit not only the research on soil sampling but all basic research on soil testing and determination of the physical properties of the soil in situ The total number of experiments required would thereby be reduced, and there would be less danger that the results contain so many variables that the various factors which govern the disturbance of the soil and its physical properties could not be segregated and definitely determined

CHAPTER 7
BORING AND SAMPLING RECORDS

7.1 General

The records of subsurface explorations and sampling operations should be clear and accurate, and they should contain not only the data required for determination of the soil profile and the location of the samples obtained but also any observations which will contribute to an estimate of the condition of the samples and of the physical properties of the soil in situ The data which the records of semi-direct and direct methods of exploration and of undisturbed sampling should contain are discussed in the following sections and illustrated by several examples

Field records of simple, routine explorations are generally prepared by the boring foreman, but it is desirable that large and difficult explorations and undisturbed sampling operations be supervised and the records prepared by an engineer who is familiar with the methods of exploration, sampling, and testing, and with the project for which the explorations are being made Such an engineer is better able to evaluate the changing requirements of the work and will often observe conditions which may appear unimportant to or escape the attention of the boring foreman, while enabling the latter to devote his entire time to the actual boring and sampling operations

7.2 Comments on Soil Classification

Many misunderstandings have been caused by the use of different soil classifications and of local or popular designations, which often cover a range of soils with considerable difference in physical properties Several attempts have been made to establish a general soil classification for civil engineering purposes, but none of the proposed classifications has yet attained universal use and approval The difficulties arise primarily from the fact that a classification which takes all the soil properties into consideration would be too complicated for general use, and that the importance of the different properties varies with the purpose for which the soil is used It will probably be necessary to establish several classifications, each adapted for particular conditions and uses of the soil However, it is to be hoped that a simplified general classification, which will be adequate for preliminary identification of the soil and as a basis for more specialized classifications, will be agreed upon in the not too distant future

Selected references on soil classifications are assembled in Section 8 of

the Classified Bibliography, and the subject is also discussed in several papers on foundation exploration and books on soil mechanics and foundation engineering. Particular attention is called to the simplified classifications and methods of field identification proposed by **Mohr (341), Casagrande (811), Rutledge (825), and Terzaghi-Peck (246).**

A simplified soil classification will seldom fully describe a given soil, and the field and office records of boring and sampling operations should contain a detailed description of the soils encountered in terms of the predominant size and shape of the grains, gradation, compactness, structure, plasticity, consistency in the undisturbed and remolded state, contents of organic matter and conspicuous minerals, etc With the aid of such a detailed description, the soil can generally be placed in any one of the currently used classifications, if so desired

The use of symbols, numbers, letters, and abbreviations instead of detailed descriptions of the various soil types and properties facilitates preparation of records and may be necessary when soil profiles are to be shown in correct position with respect to the topographical profile, Fig 160, and are closely spaced However, unless required by space limitations, symbols and abbreviations should not be used as the only means of identification, since they often are the cause of confusion and misunderstanding and make the reading of the exploration records difficult for those not thoroughly familiar with the meaning of the abbreviations

7.3 Records of Reconnaissance Borings

The field records of reconnaissance or general borings should contain the following data·

(1) Proper identification data, including the name of the project and site; coordinates or number of boring referred to a detailed map; date of start and completion of the boring; and name of the boring foreman, inspector, or engineer in charge of the work

(2) Ground surface elevation at each boring with reference to a definitely established datum which will not be affected by subsequent construction operations.

(3) Depths at which major changes in the character of the soil take place and a detailed description of the soil in each major stratum. The description should be based on examination of a representative sample, and at least one such sample should be taken in each stratum

(4) Penetration resistance of the sampler or an estimate of the compactness or consistency of the soil in situ based on the rate of progress or the feel of the boring tools.

(5) The numbers of the samples and the depths from which they are taken should preferably be given on the boring record, but this information is occasionally

JOB NO 765 DATE 3-14-1945
JOB ADDRESS X Company - 123 Y Street - Z City
FIXED DATUM USED Z City
ELEVATION OF GROUND SURFACE AT THIS BORING 142 5 FT

DEPTHS FROM	DEPTHS TO	CLASSIFICATION	BLOWS PER FT	LOST WATER
GROUND SURFACE	2'-4"	Topsoil - Organic sandy silt		
2'-4"	7'-3"	Fill - sand silt and clay with	3	
		cinders and rubbish		
7'-3"	11'-4"	Organic silty sand - loose - gray	2	X
		traces of peat		
11'-4"	13'-10"	Peat with 1/8" layers of brownish	1	
		silty sand - very soft		
13'-10"	18'-3"	Silty sand - coarse to fine	5	X
		yellow gray - loose		
18'-3"	27'-3"	Mottled yellow clay - very stiff	20	
		to stiff - breaks into lumps		
27'-3"	32'-4'	Silty clay - gray - medium -	11	
		partings of silt and fine sand		
32'-4"	56'-6"	Clay - bluish gray -	5	
		medium soft to soft		
56'-6"	68'-4"	Silty clay - olive green-medium	12	
		stiff - thin silt and sand layers		
68'-4"	73'-10"	Silty sand - gray yellow - clean -	20	X
		fine to coarse - firm		
73'-10"	78'-6"	Sandy gravel - dense	30	X
78'-6"	82'-3"	Hardpan	44	
82'-3"	86'-3"	Soft rock - decomposed shale	25	
86'-3"	88'-4"	Sound rock - dark green shale	75	
GROUND SURFACE	77	USED 2" CASING		

DEPTH TO WATER LEVEL 6'-0" FT 8'-6" FT
TIME AFTER COMPLETION 1 HOURS 18 HOURS
BLOWS PER FOOT FOR 1 STD PIPE SAMPLER DRIVEN WITH 140 LB HAMMER, 30 DROP

FOREMAN Frank Smith BORING NO 5

SIMPLE FIELD RECORD OF RECONNAISSANCE BORINGS

FIG 145

LOCATION X Company - 123 Y Street - Z City
SURFACE ELEVATION 142 5 DATUM Z City
BORING 2" Wash Boring SAMPLER 1" Std Pipe
HAMMER 140 LBS 30 " DROP DATE 3-14-1945

DEPTHS FROM	DEPTHS TO	SAMPLE	CLASSIFICATION AND REMARKS	BLOWS PER FT	WATER
0			Topsoil - Organic sandy silt		
	2 3		No sample		
2 3					
3 0	4 2	1	Fill - sand, silt and clay	3	
	7 2		with rubbish and cinders		
7 2					
7 7	8 8	2	Organic silty sand - loose - gray	2	X
	11 3		traces of peat		
11 3					
11 7	12 8	3	Peat with 1/8" layers of brown	1	
	13 8		sandy silt - very soft		
13 8					
14 3	15 5	4	Silty sand, coarse to fine	5	X
	18 2		yellow gray - loose		
18 2					
18 5	19 6	5	Mottled yellow clay - very stiff	20	
24 0	25 1	6	to stiff - breaks into lumps	10	
	27 2				
27 2					
27 8	29 0	7	Silty clay - gray - medium -	11	
	32 3		partings of silt and fine sand		
32 3					
32 8	34 0	8	Silty clay - bluish gray -	6	
39 2	40 4	9	medium to soft - silt partings	5	
45 2	46 5	10	(continued)	4	

0	USED	CASING	
DEPTH OF HOLE		15 5	
DEPTH TO WATER	5 8	6 7	7 3
TIME OF OBSERV	11 50	12 20	12 50

JOB NO 765
BORING NO 5

FOREMAN Frank Smith SHEET NO 1 of 2

FIELD RECORD OF RECONNAISSANCE BORING AND SAMPLING

FIG 146

omitted, and the samples are then marked with the number of the boring and the depth to the top and bottom of the particular stratum from which they are taken

(6) Any obstructions and difficulties encountered, such as remains of old structures and trees, stones and boulders, caving and rise of the soil in the bore hole A full record should be made of every boring, even when it is not completed on account of obstructions and other causes

(7) The depths at which a loss or inflow of water into the bore hole occurs The actual water level and the rate of its rise or fall should preferably be determined and noted

(8) Whenever possible the depth to the free ground-water level or levels and the piezometric pressure levels in artesian strata, that is, when the bore hole extends below the ground-water level and fairly pervious strata are encountered

(9) The diameter and method of advancing the bore hole When only a part of the bore hole is cased, the depth to the lower edge of the casing should be given

(10) The type and diameter of the sampler and weight and drop of the hammer or a description of other methods used to force the sampler into the soil and determine the penetration resistance The data in paragraphs (9) and (10) should at least be given in the general report on the entire exploration

Examples.- Fig 145 shows a simple form providing the minimum required information The depths at which representative samples are taken are not indicated, but it is understood that such samples were obtained from each of the strata shown on the record and are marked with the boundary depths of the respective strata. The boring method and the type and diameter of the sampler are standard for the entire job and are indicated only in the final office report on the entire exploration, Fig 153 The form shown in Fig 146 is more detailed, the samples are numbered and the depths at which they were taken are noted In thick strata samples are taken at intervals not exceeding five feet

7.4 Records of Detailed Explorations

When more or less continuous samples are taken, the details of the soil profile will be determined during the examination of the samples in the laboratory, and the principal field observations are then those concerning the location and condition of the samples. The field records of such borings should contain the following data·

(1) All data required in the field records of reconnaissance borings with special emphasis on the depths between which each sample is taken. The depths at which major changes in the character of the soil occur cannot always be determined, except indirectly by the penetration resistance, but the character of the soil in accessible parts of the sample should be indicated in the record.

(2) The type and diameter of the sampler and the inside clearance of the cutting edge. When the samples are preserved in thin-wall sampling tubes with a

LOCATION X Manufacturing Co, '23 Y Street, Z City
SURFACE ELEV 143 5 DATE 3-16-1945
FIXED DATUM Z City JOB NO 765
BORING 2½" Casing - Sampling Washing BORING NO 10
SAMPLER 2 Piston Sampler - 18 ga Tubing SHEET 1 OF 3

DEPTH	PENE-TRATION	SAMPLE NO	CLASSIFICATION AND REMARKS	PENET RESIST	SAMPLE LENGTHS GROSS	SAMPLE LENGTHS NET
0	NONE		Topsoil			
2 1			Organic sandy silt			
2 1	NONE		Fill - Sand silt, clay			
6 8			Cinders and rubbish			
7 2	2 51	1	Organic silty sand	600	2 50	2 43
9 7			Traces of peat	#		
10 3	3 52	2	Soft peat with thin strata	400	3 52	3 45
13 8			of fine sand and silt	#		
14 5	2 83	3	Silty sand - loose - traces of	750	2 80	2 58
17 3			clay - 2½ of sample lost	#		
17 8	2 48	4	Stiff yellow clay - Push 4'	750 #	2 38	2 32
20 3			Hammer 1 1' - 200 # - 24' drop	13 B'		
20 7	2 12	5	Stiff yellow clay - Push 1 2'	2000 #	2 10	2 04
22 8			Hammer 0 9 - 200 # - 24 drop	15 Bl		
23 4	3 03	6	Silty clay - gray - medium stiff -	1400	3 03	2 97
26 4			thin silt and sand strata	#		
26 8	3 51	7	Silty clay - gray - medium -	1000	3 50	3 43
30 3			silt partings	#		
30 9	3 53	8	Bluish gray clay	800	3 53	3 47
34 4			medium soft	#		
35 0	3 52	9	Bluish gray clay	600	3 51	3 45
38 5			soft - appears brittle	#		

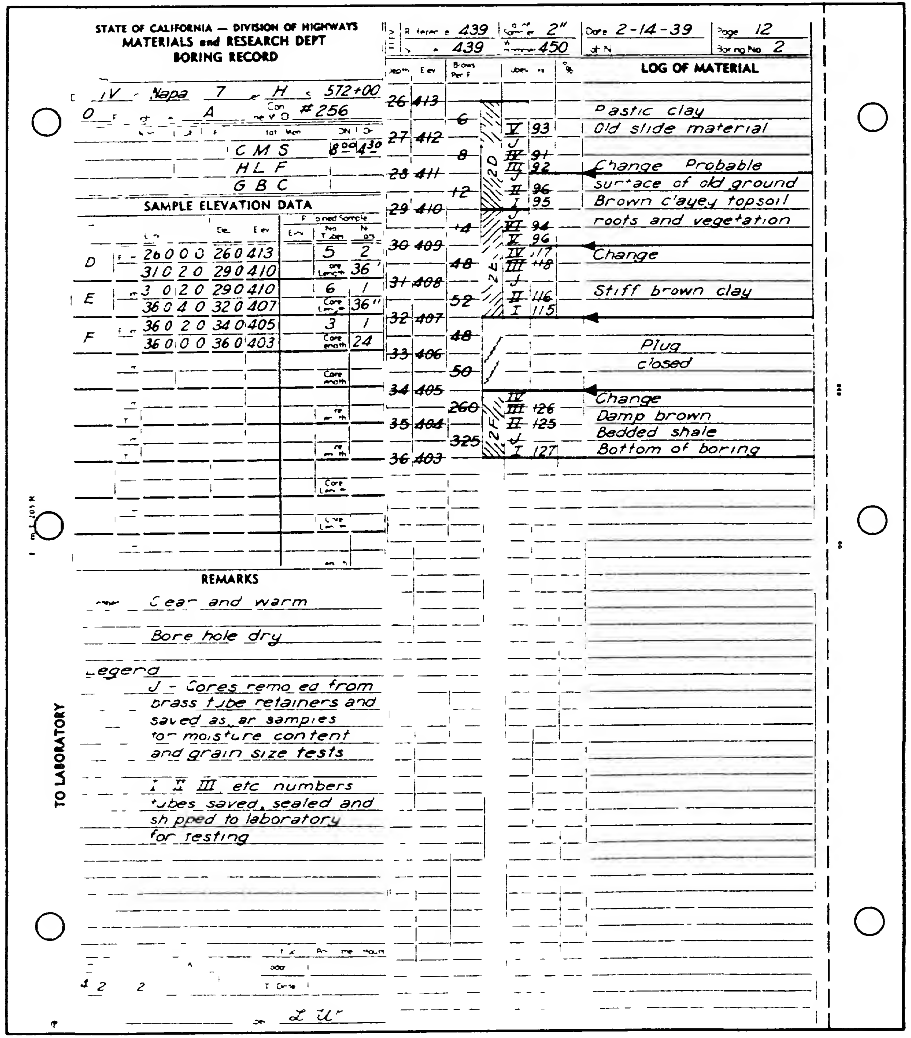
Soil classifications refer to bottom of samples

GROUND WATER OBSERVATIONS			
DEPTH OF HOLE	17 0		
DEPTH TO WATER	7 20	8 05	8 60
TIME OF OBSER	11 30	- 12 05	- 12 40

Frank Smith
FOREMAN

R Jones
INSPECTOR

FIG 147 - FIELD RECORD FOR DETAILED EXPLORATION



RECORD SPECIALLY ADAPTED FOR USE WITH 2 PORTER PISTON SAMPLER

FIG 148 - CALIFORNIA FIELD BORING AND SAMPLING RECORD

built-in cutting edge, the inside clearance may be determined in the laboratory.

(3) The method or methods used to force the sampler into the soil The penetration resistance should preferably be determined and recorded When more than one method of driving is used in a single operation, the depth of penetration and the penetration resistance obtained by each method should be noted

(4) The depth of penetration, determined with an error not exceeding one half of one percent For an open sampler the depth of penetration should include the initial penetration of the sampler under the weight of the drill rods and the sampler.

(5) The gross or original length of the sample, determined with an error not exceeding one half of one percent When samplers with core retainers are used, the downward movement of the sample in activating the core retainer should be taken into consideration in computing the gross length

(6) The net length of the sample, determined with an error not exceeding one quarter of one percent When other control tests are made, the results should, of course, be recorded

(7) Unsuccessful sampling operations should be recorded with the same care and detail as successful operations Efforts should be made to ascertain the causes of loss of a sample

Examples.- The form shown in Fig 147 is primarily intended for use with samplers of thin-wall tubing The single depth column and separate column for the penetration resistance, compared with the double depth columns used in Fig 145 and 146, have the advantage that computation of both the lower depth and the recovery thereby are facilitated Furthermore, the penetration should, in this case, be determined to the nearest 0 01 ft, whereas it is sufficient to indicate total depths to the nearest 0 1 ft Each sampling tube should be marked with job, boring, and sample number and preferably with a label containing the principal details of the operation, see Fig. 333. A full-page form with space for depth computations, preliminary soil profile, time record, and other details is shown in Fig 148 It was specially devised for use with the Porter piston samplers, Fig 218 and 219, but can be adapted to any type of sampler

7.5 Records of Special Explorations

Field records for large-diameter borings in which undisturbed samples are obtained should contain the same data as those for the detailed explorations, but all measurements during the sampling operations and observations concerning the condition of the sample assume increased importance and should be recorded in greater detail. Separate field records of all measurements and computations are often made for each undisturbed sample, Fig. 149. The computations must be made in any case, and an orderly recording of all the data instead of only the results tends to eliminate mistakes and omissions and permits checking later

LOCATION Mill River Bridge - West Abutment		
SAMPLER 4 3/4" Piston - Liner I D = 468"	PROJECT NO 564	
CUTTING EDGE D = 4 61 - C_i = 1 5 %	BORING NO 3	
DRIVING Block and Tackle	SAMPLE NO 5	
WATER IN HOLE Casing full	DATE 5-20-1946	

A	TOTAL LENGTH OF CASING		13 64
B	CASING ABOVE GROUND		1 60
C	DEPTH BOTTOM OF CASING	C = A - B	12 04
D	LENGTH OF CLEAN-OUT AUGER AND RODS		15 00
E	RODS ABOVE GROUND		2 32
F	DEPTH OF HOLE	F = D - E	12 68
G	LENGTH OF SAMPLER AND RODS		20 00
H	RODS ABOVE GROUND - START OF DRIVE		7 18
I	DEPTH TO TOP OF SAMPLE	I = G - H	12 82
J	PENETRATION OF CLOSED SAMPLER	J = I - F	0 14
K	RODS ABOVE GROUND - END OF DRIVE		1 75
L	DEPTH BOTTOM OF SAMPLE	L = G - K	18 25
M	NET DEPTH OF PENETRATION	M = H - K	5 43
N	SETTLEMENT OF RELEASED PISTON		0 04

PENETRATION RESISTANCE 400 to 2400 lbs

RECOVERED SAMPLE								
GROSS LENGTH = M - N = 5 39					RECOVERY 99 2%			
SECTION		A	B	C	D	Shoe	
NET LENGTH		0 72	1 50	1 50	1 45	lost	
FIELD TEST 5/8" ⌀ 1 1/4"	U C q_u		0 35	0 95	0 75		kg/cm²
	WEIGHT		11 52	11 81	11 68		g
	γ (WET)		112	115	114		lbs/cu ft
SOIL	A-B = Gray clayey silt - sand seams						
	B-D = Silty clay - Yellow gray - Med stiff						
	D = Silty clay - Olive gray - Med soft						

TIME RECORD	CASING ADVANCED	CLEANING FINISHED	START DRIVE	PENETRATION TIME	START WITHDRAWAL
	1 10	1 35	1 55	7"	2 10

NOTES

WEATHER Cloudy - mild

Lower 0 22' lost at silt parting

5/8" ⌀ x 1 1/4" Control test specimens taken from top of liner sections

FOREMAN S White INSPECTOR C Black

DETAILED FIELD RECORD OF UNDISTURBED SAMPLING

FIG 149

LOCATION Mill River Bridge - West Abutment		PROJECT NO 564
SURFACE ELEV 423 4	FIXED DATUM M S L	BORING NO 3
BORING 6" Casing - Franks Drill Rig No 11		SHEET 1 OF 4
SAMPLERS 2' Split Barrel - 4 3/4" Piston Sampler		FOREMAN S White
SAMPLES J = Jar, P = Paraffined, L = 4 68" I D Liner		INSPECTOR C Black
DATE START 5-20-1946	DATE FINISH 5-24-1946	

SOIL PROFILE DESCRIPTION	DEPTH	DEPTH SCALE	TYPE	SAMPLES NO	DEPTH	REC	FORCE	BORING AND SAMPLING NOTES
	G S	0						
Topsoil								5-20-1946 - cloudy-mild
Org clayey silt	1 3							
								Hole to 4 5 - auger
Clayey silt								
medium - dark			J	1	2 5			Casing to 4 6
gray - seams of								
brown sand	3 8							Sample 1 with auger
								Hole to 9 0 - auger
Gray sandy silt		5	J	2	5 0			
	5 7							Sample 2 with auger
								Sample 3 with auger
Medium-fine sand			J	3	7 0			
Yellow gray								Casing to 9 2
Medium dense								Hole to 10 4 - bailer
Streaks of coarse				GW	8 3	5-20	-1946	
sand, little gravel								Water 9 9 87 8 5
								Time 11 45 12 05 12 25
	10 2	10						River Stage 15 6
								River Elev 411 7
Gray silty sand			J	4	10 4	12	15	
with a little clay					11 6	11	Bl/Ft	Sample 4 - 2" split barrel
	11 8							Hammer 200#, Drop 24"
Gray clayey silt								Casing to 12 0
sand seams			P	5-A	12 82			Casing filled with water
								Cleanout to 12 7 with
	14 3		L	5-B				Calyx jet auger
		15				5 43	400	
Silty clay						5 39	to	Sample 5
Yellow gray			L	5-C		99 2 %	2400 lbs	4 3/4" Piston sampler to
Medium stiff								18 25 with block and
	17 2							tackle in 7 seconds
			L	5-D				0 22' bot sample lost
				Lost	18 25			
Silty clay								Casing to 17 9
Olive gray								Cleanout to 18 5
Medium soft			P	6-A	18 65			with Calyx jet auger
		20	L	6-B				

GENERAL FIELD RECORD OF EXPLORATION AND UNDISTURBED SAMPLING

FIG 150

In addition to large-diameter undisturbed samples of specially designated strata, undisturbed samples of small diameter or representative samples are often taken of all the principal strata so that a detailed soil profile can be prepared and the field classification of the soils can be checked in the laboratory without breaking the seals of the large undisturbed samples The number, depths, and types of all these samples should, of course, be noted in the general field record for each boring in addition to ground-water observations and other data Such a general record, Fig 150, would be rather complicated unless the details concerning the large undisturbed samples are given on separate sheets

The field records of explorations by means of and sampling in test pits and other types of accessible explorations should contain the following data

(1) Identification data, ground surface elevation, etc , as for borings

(2) Dimensions, types of sheeting and other methods of stabilization, methods of advancing the exploration, such as hand tools, air tools, blasting, boring, etc

(3) The ground-water level, if encountered, methods of controlling the water, quantity of inflow or required capacity of pumps

(4) A soil profile with detailed description of the various strata, their strike and dip, seams, pockets, planes of failure, distortions, and other irregularities The orientation of the wall shown in the profile should be indicated, and the inclination of the strata in an adjacent wall should be given so that the dip and strike of the strata can be computed, if they are not determined directly in the field

(5) The location and type of all samples taken The location of minor and major field tests should also be shown even though the details may be recorded separately

(6) Plastic movements, loss of ground, visible disintegration or slaking, and other sources of disturbance of the soil of which large undisturbed samples are taken, see Section 2 18

(7) The results of control tests on large undisturbed samples, such as weight, unconfined compression tests, cone penetration tests These data should preferably also be given on the label of the sample

Example.- For the purpose of showing the various notations, a record of a test pit exploration in a hypothetical sequence of soil strata has been prepared and is shown in Fig 151 The consistency of the cohesive strata is assumed determined in the field by means of unconfined compression tests on small samples, see Fig 357, and these tests also serve as control tests for the large samples It is generally also advantageous to keep a detailed time and cost record, since such a record indicates the period of exposure of the various strata and facilitates estimating the cost of the actual foundation excavation.

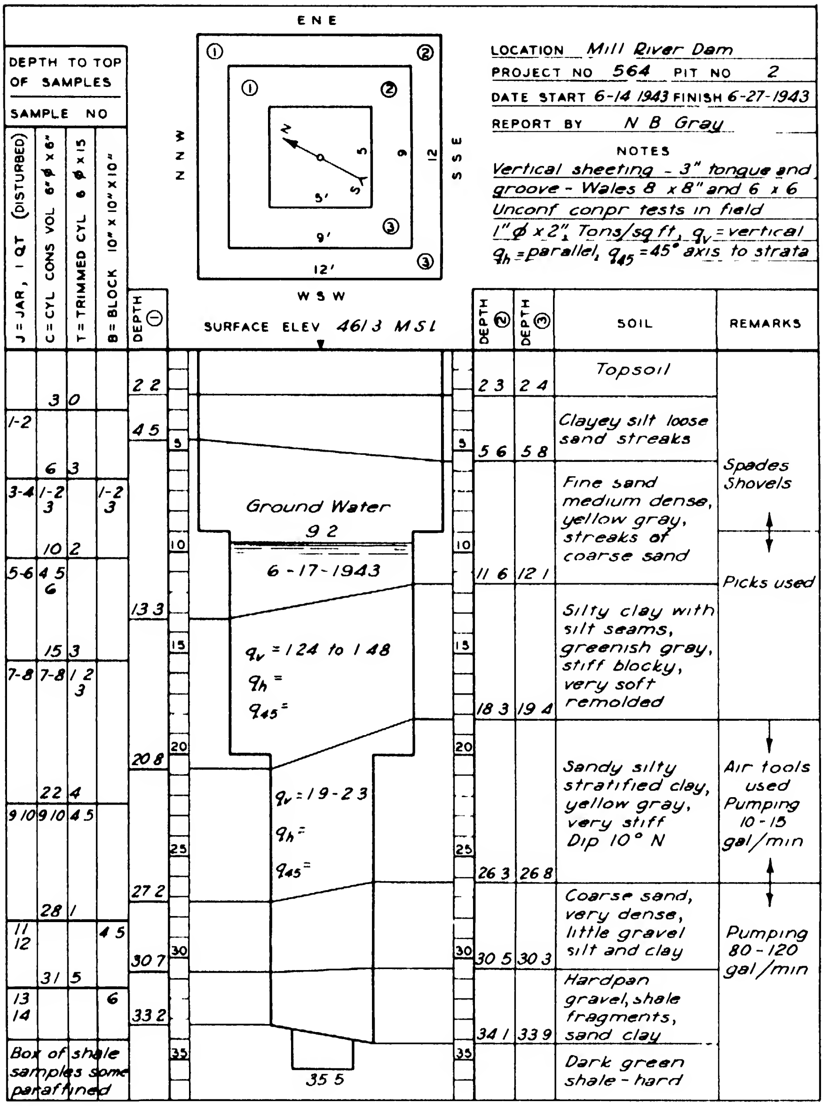


FIG 151 - RECORD OF TEST PIT EXPLORATION AND SAMPLING

7.6 Office and Laboratory Reports

When the field records and samples from reconnaissance borings are received in the laboratory, the field classifications of the various strata should be checked against the samples and corrected when necessary The data are then assembled in a final or office report or plotted as soil profiles Two examples of office reports on reconnaissance borings, based on forms used by the Raymond Concrete Pile Company, are shown in Fig 153 and 154 and correspond to the field records shown in Fig 145 and 146.

Continuous samples of small diameter, obtained in detailed explorations, are removed from the sampling tubes or liners, sliced, examined, and subjected to classification and other minor physical tests It is advisable to prepare a separate

report on the examination of and tests on each sample, and such a report should contain the following data·

(1) Identification data similar to the field records, and including the dates of both the sampling and the laboratory examination

(2) The principal sampling data, such as the type and diameter of the sampler, inside clearance and condition of cutting edge, depths of sampling, depth of penetration, gross length, and the net length as measured in both the field and the laboratory.

SAMPLER	2" Piston - 18 ga Tubing	PENETRATION	3 63	PROJECT NO	167
CUTTING EDGE	C_i = 1 3 %, small dent	GROSS LENGTH	3 55	BORING NO	5
DRIVING	Pushing - 900 lbs	RECOVERY %	97 2	SAMPLE NO	9
DATE OF SAMPLING	7-15-1943	NET LENGTH FIELD	3 42	DEPTH FROM	52 2
DATE OF LAB EXAM	7-25-1943	NET LENGTH LAB	3 43	DEPTH TO	55 8

SECTION	TUBE LENGTH	CONDITION	SKETCH	CONSISTENCY NAT	CONSISTENCY REM	DESCRIPTION OF SOIL	LABORATORY TESTS W %	q nat rem ts/sq ft	LIM LL PL PI	OTHERS
A	0 5					0 45' empty 0 05' silty sand				
B	0 5	0.2' dist rest fair		Med dense		Yellow gray sand Med to fine - stratified 1/16" silt layers	27 2			M A
C	0 5	fair to good				0 15' as above 0 35' as below	40 5	1 20		
D	0 5	good		stiff and brittle	very soft sticky	Dark gray greenish silty clay - uniform wet - stratified dried Dip of layers 15°	41 7	1 29 0 12	50 3 25 7 24 6	
E	0 5	good				0 4' as above 0 1' as below	39 8	1 17		
F	0 5	good		Med stiff Tough	soft	Medium gray silty clay - stratified	35 7	0 88 0 29		
G	0 5	good Shear				As above Dip of layers 20°	32 5	0 81	43 3 23 9 19 4	
H	0 5	surface cracks dist		Med soft	soft	0 44' as above 0 06' Paraffin plug	34.8			
TOTALS	4 0	TUBE	REMARKS			All tube sections removed by hand Some adhesion of soil in sections C and H, rest clean	LABORATORY REPORT BY			
	3 43	SAMPLE					D D Brown			

FIG 152 - RECORD OF LABORATORY EXAMINATION OF LONG SAMPLES

(3) The force required to remove the sample sections from the tubing or liners, when this force is so great that it may cause disturbance of the sample or so small that it indicates excessive clearance of the cutting edge.

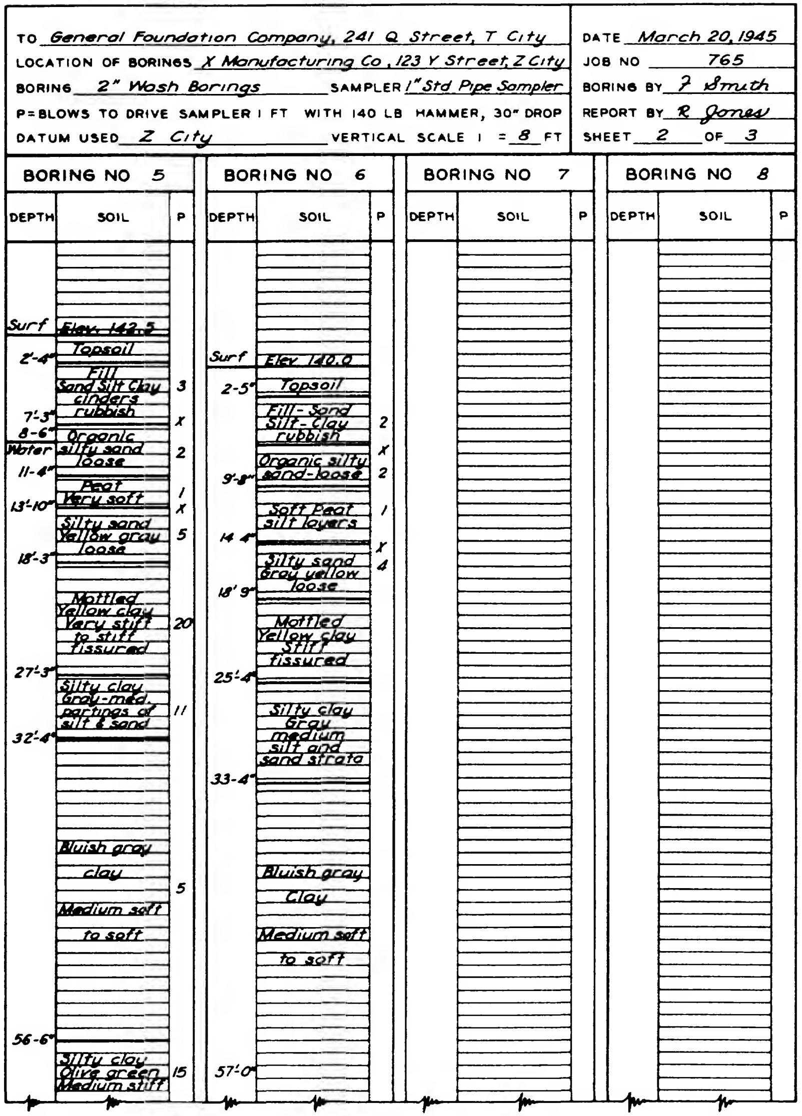


FIG 153 – OFFICE REPORT ON RECONNAISSANCE BORINGS

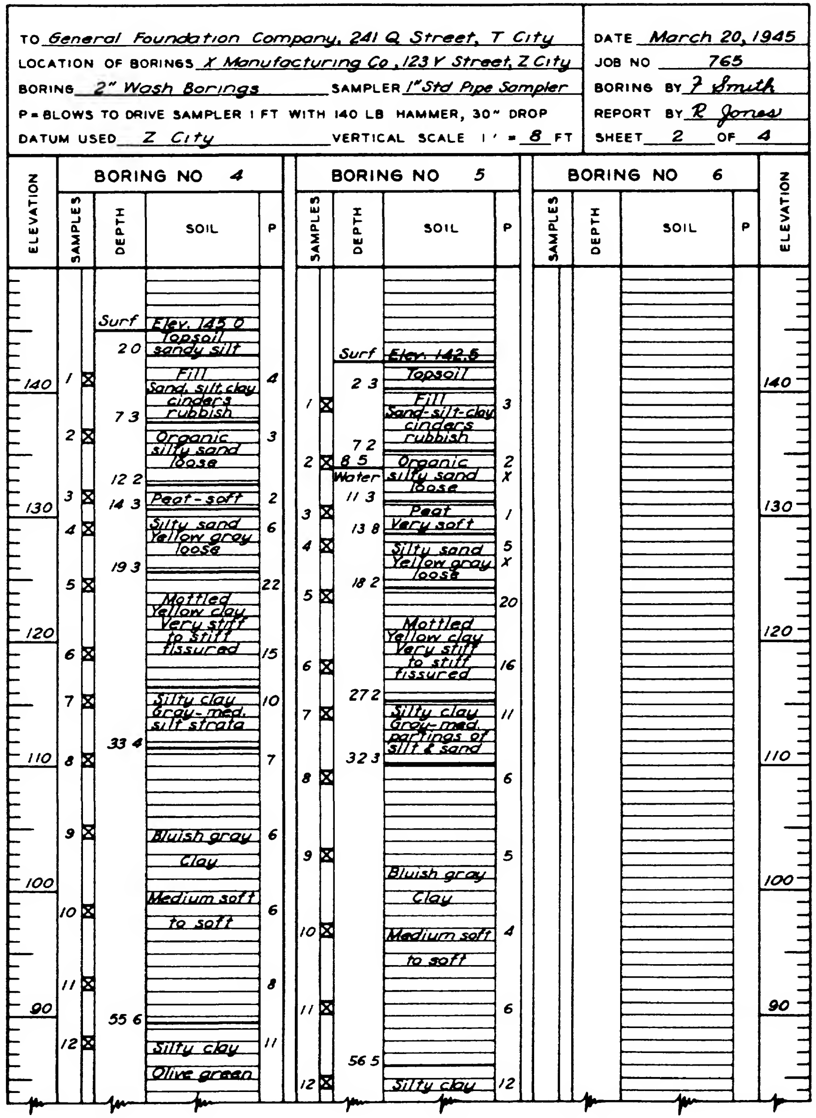


FIG 154 – OFFICE REPORT ON RECONNAISSANCE BORING AND SAMPLING

(4) Signs of disturbance on the tubing and the surface of the sample, such as drying on account of defective sealing, corrosion and discolorations, adhesion of soil to the tubing, slumping on account of vibrations, planes of failure in or excessive softness of sections of the sample

(5) Distortions and planes of failure in sliced and partially dried sections of the sample. It should be indicated when it is probable that such disturbances are not caused by sampling but found in the soil in situ

(6) A detailed description of the soil, including its consistency in the natural and remolded state and the estimated dip of stratifications

(7) The tests performed on various sections of the sample and the principal results of such tests

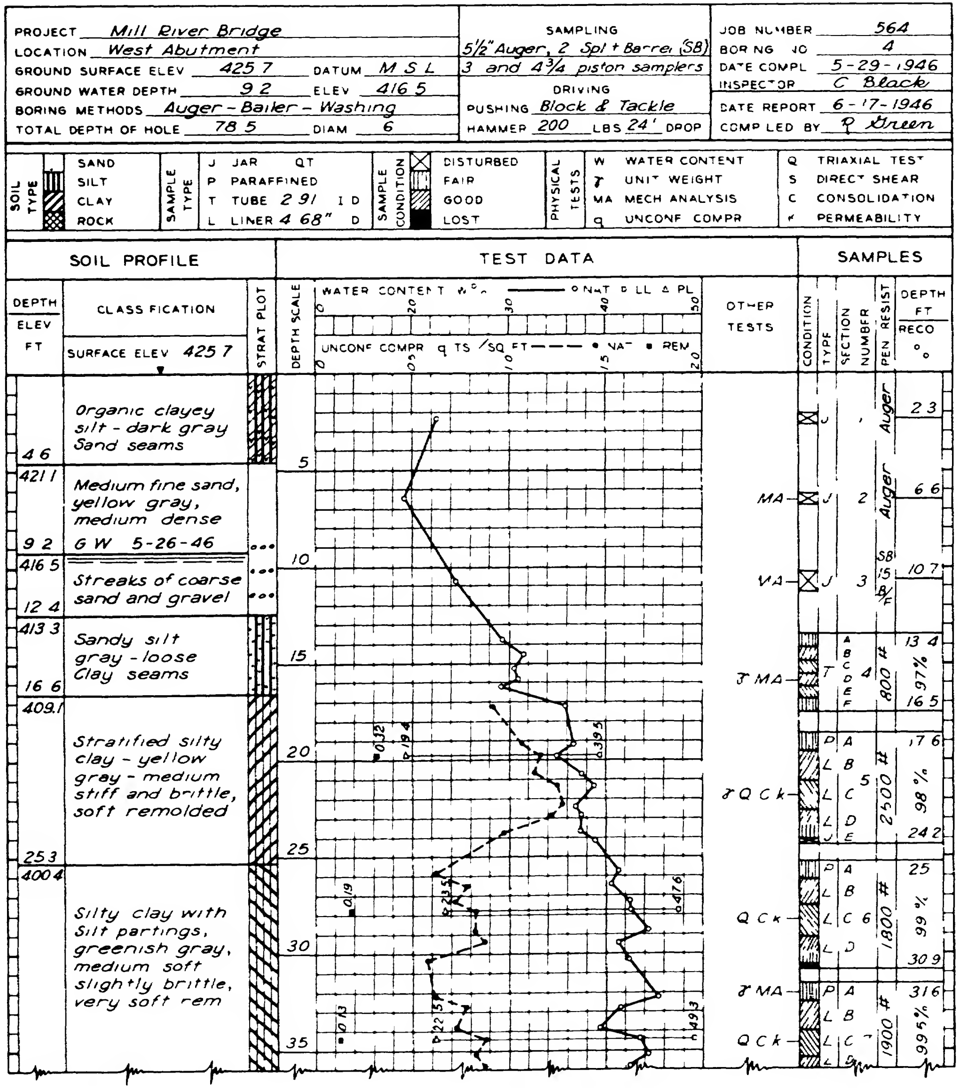
An example of such a record of the laboratory examination and classification tests on a sample obtained with a 2-in thin-wall piston sampler and cut into 6-in sections is shown in Fig 152 Distortions and planes of failure are indicated by sketching instead of description Water contents, Atterberg limits, and unconfined compressive strengths are shown in this record but may, of course, be supplemented or replaced with other test data when so desired

Samples obtained in special explorations are likewise examined in the laboratory and subjected to classification and other minor physical tests However, seals of the large undisturbed samples are broken only when it is necessary to examine such samples in order to establish the soil profile, and the samples are not removed from their containers before they are to be tested, in which case the control tests performed in the field are repeated in the laboratory The results of the examination and preliminary tests may be given on a record similar to the one shown in Fig 152, but forms similar to the field record and with separate columns for field and laboratory classifications of the soil are also used

The field and laboratory records are generally combined in a single final record or office report on each boring An example of such a report is shown in Fig 155. It contains space for stratigraphical and physical profiles with the latter indicating the results of the minor physical or classification tests The depth to, condition of, and major physical tests to be performed on each sample section are also given These profiles as well as the indication of the probable condition of the sample sections facilitate the selection of the appropriate sections for major physical tests

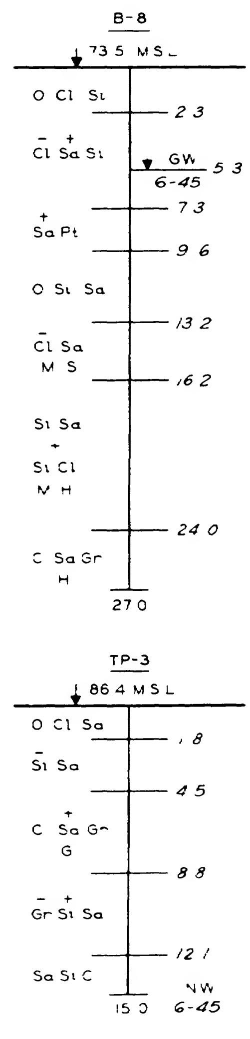
7.7 Stratigraphical Soil Profiles

Results of subsurface explorations for large projects are generally presented in a condensed form as soil and rock profiles on the basic drawings for the project. Many forms of profiles, symbols, and abbreviations are used to reduce the work and space required or to emphasize the principal types of foundation materials.



OFFICE REPORT ON DETAILED EXPLORATION AND UNDISTURBED SAMPLING

FIG 155



BASIC SOILS

Bo = BOULDERS
St = STONES
Gr = GRAVEL
Sa = SAND
Si = SILT
Cl = CLAY

BASIC ROCKS

Gt = GRANITE
Ba = BASALT
Ss = SANDSTONE
Sn = SHALE
Sl = SLATE
Ls = LIMESTONE

IN COMPOSITE SOILS THE PRINCIPAL TYPE IS GIVEN LAST

Sa Si = SANDY SILT — Si Cl = SILTY CLAY

A + OR − SIGN INDICATES LARGE OR SMALL QUANTITIES

$\overset{+}{\text{Sa}}$ Si = VERY SANDY SILT — $\overset{-}{\text{Sa}}$ Si = SLIGHTLY SANDY SILT

ALTERNATING THIN LAYERS OR LAMINAE ARE INDICATED BY

Si + Cl = ALTERNATING LAMINAE OF SILT AND CLAY

SPECIAL SOIL TYPES

Ts = TOPSOIL
Fi = FILL
Pt = PEAT
Ls = LOESS
Ma = MARL
Ha = HARDPAN

MODIFIERS

C = COARSE
M = MEDIUM
F = FINE
R = ROUNDED
A = ANGULAR
G = GRADED
U = UNIFORM
S = SOFT - LOOSE
H = HARD - DENSE
P = PLASTIC
B = BRITTLE
O = ORGANIC
D = DECOMPOSED
I = INDURATED

GENERAL

B = BORING
TP = TEST PIT
GW = GROUND WATER
NW = NO WATER

SOIL PROFILE WITH ABBREVIATED DESCRIPTIONS

FIG 156

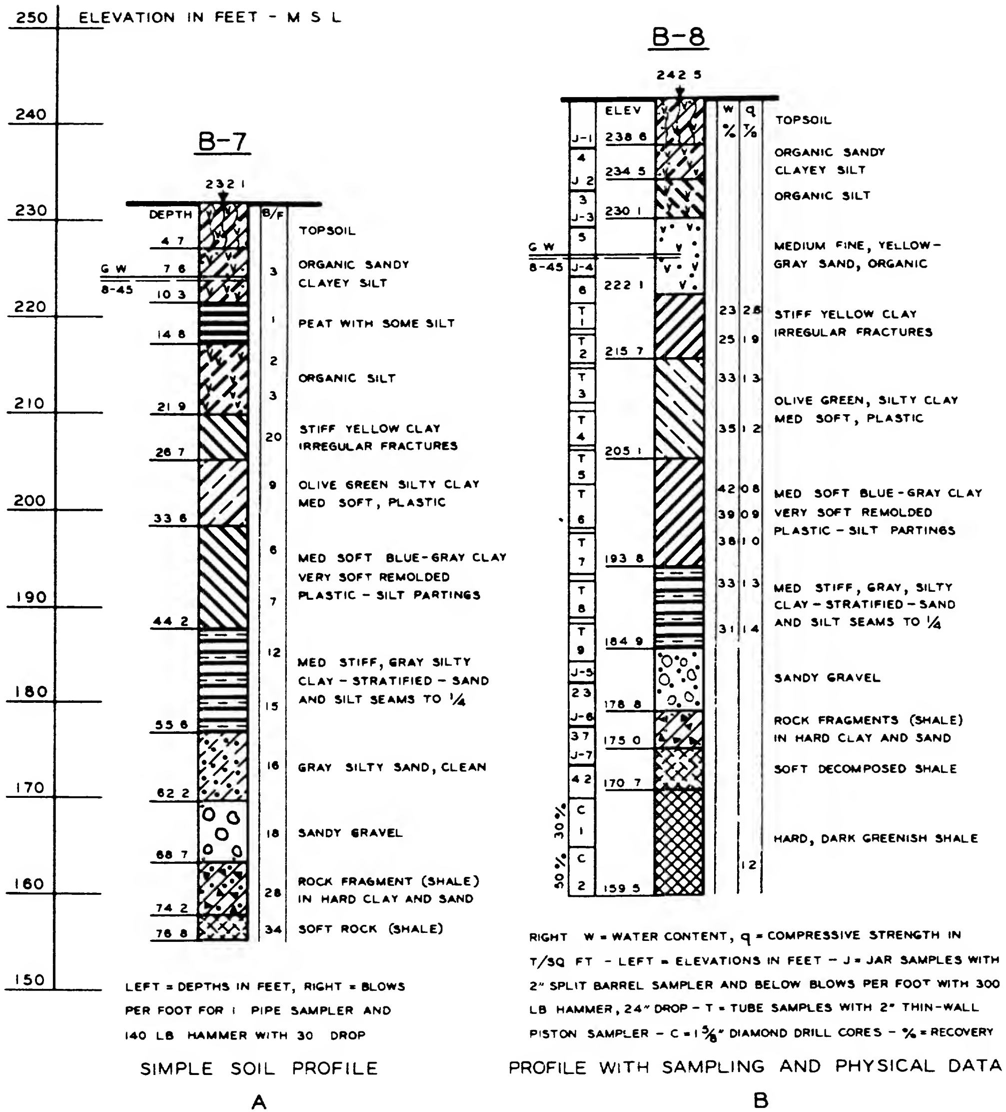


FIG 157-SOIL PROFILE - SYMBOLS AND DESCRIPTIONS

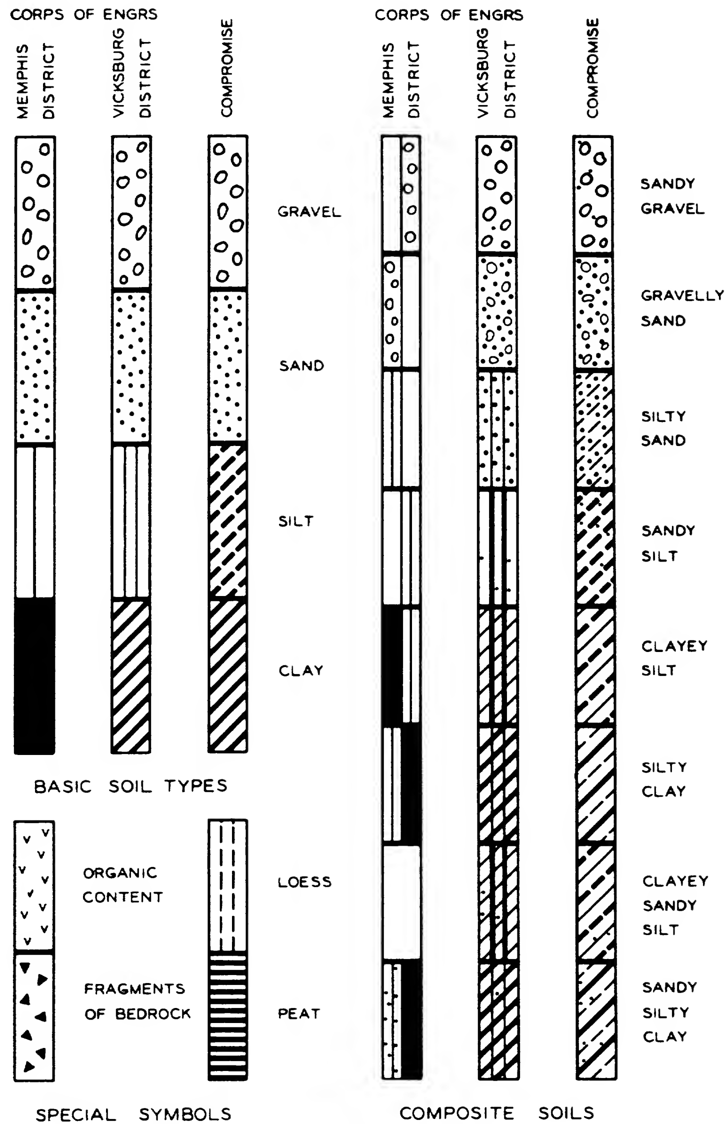


FIG 158-VARIOUS SOIL SYMBOLS

A form of soil profile which is reduced to the bare essentials, Fig. 156, was developed for presentation of the results of explorations for the German superhighways (206, 315, 317). The character of the strata is indicated by standardized abbreviations and symbols, and in adapting these abbreviations to English, the writer used two-letter abbreviations for soil and rock types and single-letter abbreviations for indicating specific properties. In describing composite materials, the minor component is given first and the major last A further indication of the relative quantities of the component materials is obtained by placing a plus or minus sign over the respective letter symbols, whereas a laminated or varved structure is indicated by placing a plus sign between the symbols for the materials in the laminae

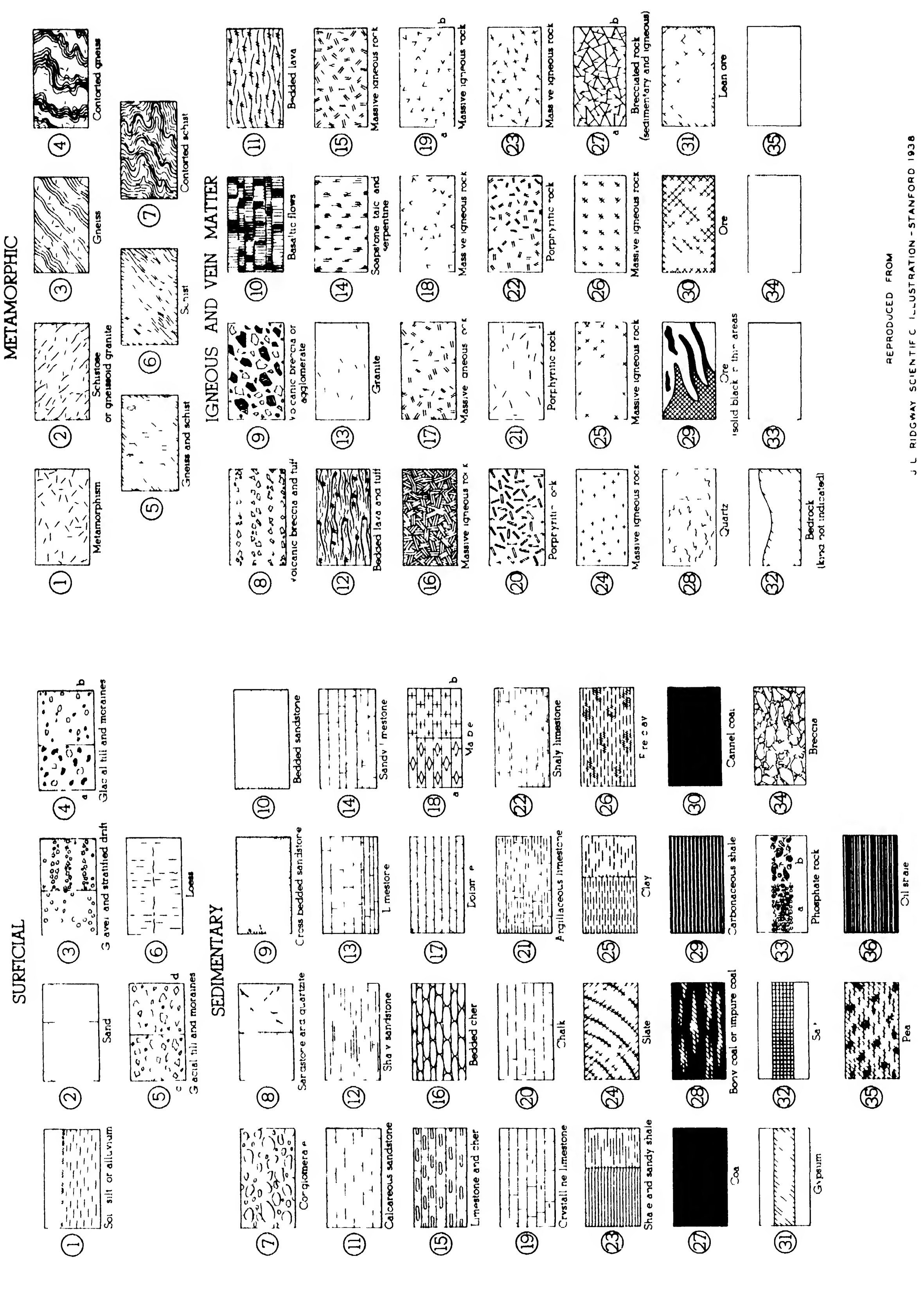
As previously indicated, it is difficult to devise a classification system or symbols which will serve equally well all the purposes for which soil is used In the airfield classification system for soils, developed by **A. Casagrande (811)** for the Corps of Engineers, the following single-letter abbreviations are proposed

G	Gravel	W	Well graded
S	Sand	P	Poorly graded
M	Silt	L	Low compressibility
C	Clay	H	High compressibility
Pt	Peat	O	Organic matter

Other abbreviations, currently used by the Corps of Engineers in presenting the results of foundation explorations for dams and similar structures, are shown in Fig 160

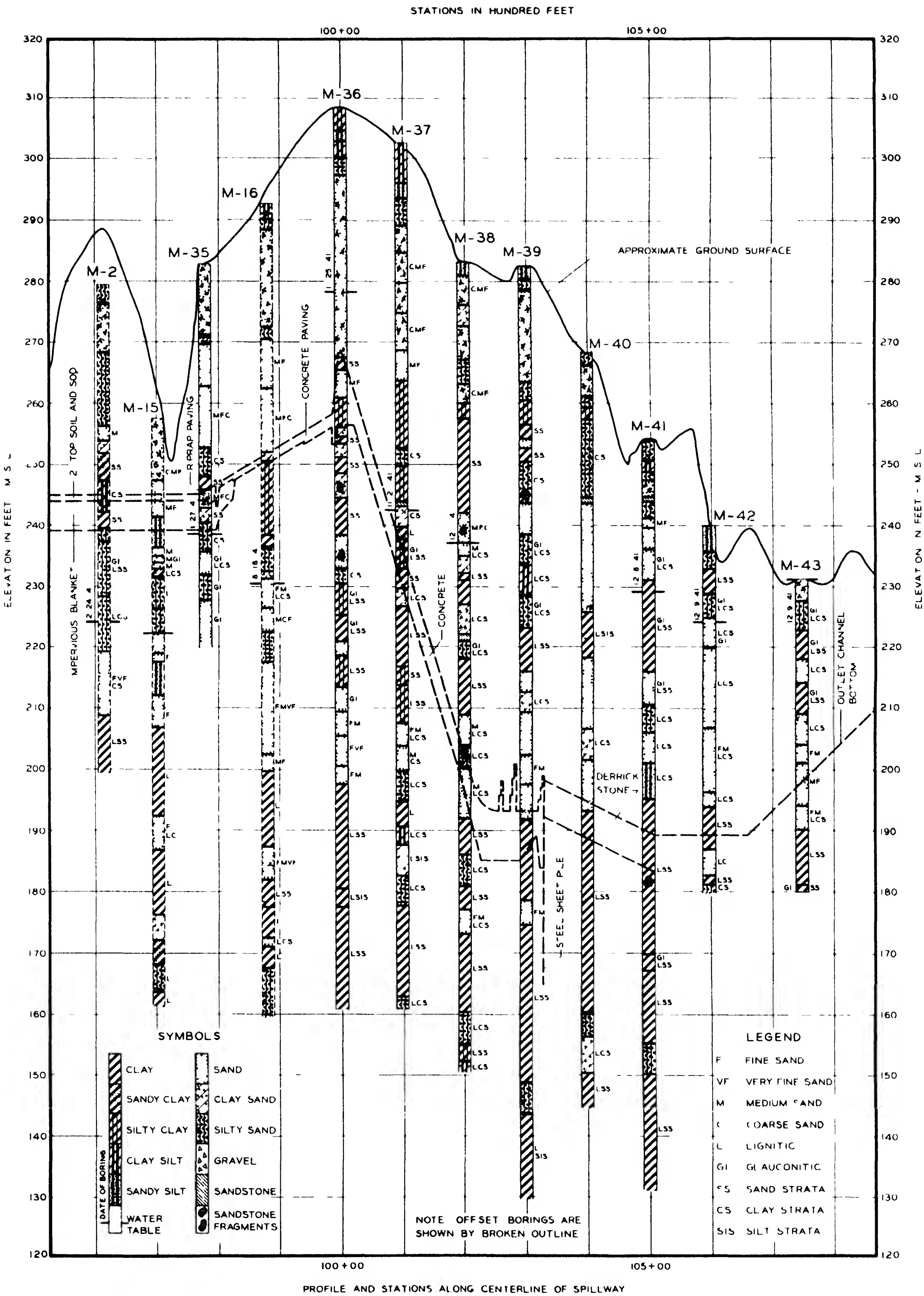
Preparation of soil profiles of the type shown in Fig 156 requires a minimum of work, but they lack clarity and detail and are difficult to read Profiles of the type shown in Fig 157 are generally preferred in spite of the extra work their preparation requires In these profiles the various strata are not only described in detail but are also indicated by conspicuous symbols which facilitate a quick, general conception of the soil conditions and emphasize critical strata As shown, sampling and physical data are often added to such profiles

A great variety of soil symbols is currently used, some of which are shown in Fig 158. The symbols for gravel and sand have become fairly well standardized Clay is usually indicated by inclined, solid-line cross hatching and silt often by inclined dotted-line cross hatching The Vicksburg District, Corps of Engineers, uses vertical lines as a symbol for silt, and has further proposed that the predominant component of composite soils be shown with heavy lines and the lesser components with thin lines. The Memphis District uses solid black as a symbol for clay and a single, vertical line for silt. The profile column for composite soils is divided into two parts, and the symbol for the predominant component is shown on the right side. The solid black symbol for clay is easy to draw, but it does not permit indication of composite soils with three component parts in which clay is one of the lesser components. The preparation of profiles with soil symbols is greatly facilitated by having the various symbols printed on transparent, gummed paper, known under the



LITHOLOGIC SYMBOLS COMMONLY USED IN GEOLOGICAL REPORTS

FIG 159



BASED ON DRAWING BY MISSISSIPPI RIVER COMMISSION CORPS OF ENGINEERS

FIG 160 - SOIL PROFILES PLOTTED ON THE TOPOGRAPHICAL PROFILE

trade name Zip-A-Tone, which is cut to the required size and attached to the drawing by a light pressure. However, the gummed paper may be displaced or damaged by repeated passing of the drawing through a printing machine, and the method is primarily used when photographic reproduction negatives are made from the original drawings.

When the borings are extended only a short distance into rock, the latter is often indicated on the profiles by solid black or double cross hatching. When various types of rock are to be indicated in the profiles, the symbols are generally patterned after those used by geologists. The lithologic symbols most commonly used in geologic reports have been assembled by **Ridgway (238)** and are shown in Fig 159.

The conception of the foundation conditions in a certain vertical plane is greatly facilitated by plotting the soil profiles, located in this plane, in their correct vertical and horizontal position with respect to the topographical profile, Fig. 160 On account of space restrictions and since the principal purpose is to show the general character of the foundation conditions, a detailed description of the various strata is omitted, but qualifying letter symbols or physical data of particular importance are often added to the main symbols

The soil profiles described above are one-dimensional Continuous or two-dimensional profiles may be obtained by mapping in test trenches or by continuous seismic profiling, but they are generally prepared by interpolation between one-dimensional profiles Two-dimensional profiles are generally simplified and show only a few principal soil types, which are indicated by symbols or colors Average values of the physical constants for the various strata shown in the profile are often superimposed on the symbols When further details on the physical properties are needed, separate two-dimensional physical profiles -- each showing the variations of a single physical property, such as water content, unconfined compressive strength, and permeability -- are prepared by interpolation between the corresponding one-dimensional physical profiles

A conception of the foundation conditions for the entire area under investigation is obtained by interpolation between several two-dimensional profiles or between one-dimensional profiles not located in a straight line. The results of such an interpolation may be represented by contour maps or relief maps, each showing the elevation of a certain critical stratum; such maps are occasionally used when the project is very important and the foundation conditions are complicated

The accuracy of interpolated, continuous profiles or relief maps depends on the uniformity of subsurface conditions and the spacing of the one-dimensional profiles, and the interpolation may result in serious errors when the spacing of the borings is too large or the soil conditions are erratic. Therefore, when the results of subsurface explorations are incorporated in specifications and contracts, only the actual observations should be shown

PART II
DETAILS OF SAMPLING EQUIPMENT AND METHODS

CHAPTER 8
CASING AND DRILL RODS

8.1 General

The design of drive samplers and core barrels is to a certain extent governed by the dimensions of the various types of pipe and couplings which are used for casing and drill rods Some of these dimensions can be found in most engineering handbooks, but other dimensions are given only in special handbooks and catalogues, which often are not available when needed The commonly used types of casing and drill rods and their couplings or joints are therefore discussed briefly in the following sections and the dimensions given in sufficient detail for the general design of sampling equipment

8.2 Standard Pipe and Couplings

The dimensions of Standard Weight and Extra Strong Welded Pipe and their common couplings are shown in Fig 161 Since this pipe is relatively cheap and readily available in all parts of the country, it is used to a great extent as casing for shallow exploratory borings in soil. The nominal sizes most often used for casing are 2, 2-1/2, 4, 6, and 8 in The nominal sizes 1, 1-1/2, and 2 in are often used as drill rods in wash and auger borings and with drive samplers. The Extra Strong Pipe is generally preferred to Standard Pipe, since it is better able to withstand repeated use A further increase in strength and durability is obtained by replacing the welded pipe with seamless steel tubing, which is furnished with the same dimensions and threads

The standard couplings, Fig 161, are nearly always replaced with recessed couplings, Fig 162, which furnish better protection of the threads Casing with internal and external flush joints is easier to advance and pull than casing with outside couplings, and such joints are preferred when the casing must be advanced by a combination of pushing, rotation, and jetting in order to avoid the vibrations caused by blows of a drop hammer Flush joints for pipe with dimensions shown in Fig 161 must be made to order, and an example of such a joint is shown in Fig. 163. Extra

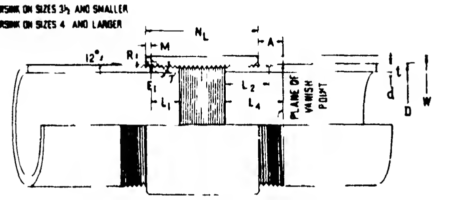
Size Nominal	Weight per foot: Nominal Threads and couplings	Weight per foot: Plain end	Pipe: Thickness	Pipe Diameters: Out side	Pipe Diameters: In side	Threads per inch	Couplings: Length	Couplings: Out side Diameter	Couplings: Weight	Test Pressure: Butt welded	Test Pressure: Lap-welded or Grade A Seamless	Test Pressure: Grade B Seamless
Ins	Lbs	Lbs	Ins	Ins	Ins		Ins	Ins	Lbs	Lbs per sq in		
1/8	24	24	068	405	269	27	13/16	563	03	700	700	700
1/4	42	42	088	540	364	18	1 3/16	719	07	700	700	700
3/8	57	57	091	675	493	18	1 3/16	875	09	700	700	700
1/2	85	85	109	840	622	14	1 9/16	1 063	17	700	700	700
3/4	1 13	1 13	113	1 050	824	14	1 5/8	1 313	26	700	700	700
1	1 68	1 68	133	1 315	1 049	11 1/2	2	1 576	40	700	700	700
1 1/4	2 28	2 27	140	1 660	1 380	11 1/2	2 1/16	1 900	48	800	1000	1100
1 1/2	2 73	2 72	145	1 900	1 610	11 1/2	2 1/16	2 200	67	800	1000	1100
2	3 68	3 65	154	2 375	2 067	11 1/2	2 1/8	2 750	1 05	800	1000	1100
2 1/2	5 82	5 79	203	2 875	2 469	8	3 1/8	3 250	2 09	800	1000	1100
3	7 62	7 58	216	3 500	3 068	8	3 1/4	4 000	3 35	800	1000	1100
3 1/2	9 20	9 11	226	4 000	3 548	8	3 3/8	4 625	4 82		1200	1300
4	10 89	10 79	237	4 500	4 026	8	3 1/2	5 000	4 61		1200	1300
5	14 81	14 62	258	5 563	5 047	8	3 3/4	6 296	8 52		1200	1300
6	19 18	18 97	280	6 625	6 065	8	4	7 390	11 27		1200	1300

A-STANDARD WEIGHT

Size Nominal	Weight per foot plain end	Thickness	Diameters: Outside	Diameters: Inside	Test pressure: Butt welded	Test pressure: Lap-welded or Grade A Seamless	Test pressure: Grade B Seamless
Ins	Lbs	Ins	Ins	Ins	Lbs per sq in		
1/8	31	095	405	215	850	850	850
1/4	54	119	540	302	850	850	850
3/8	74	126	675	423	850	850	850
1/2	1 09	147	840	546	850	850	850
3/4	1 47	154	1 050	742	850	850	850
1	2 17	179	1 315	957	850	850	850
1 1/4	3 00	191	1 660	1 278	1100	1500	1600
1 1/2	3 63	200	1 900	1 500	1100	1500	1600
2	5 02	218	2 375	1 937	1100	1500	1600
2 1/2	7 66	276	2 875	2 323	1100	1500	1000
3	10 25	300	3 500	2 900	1100	1500	1600
3 1/2	12 51	318	4 000	3 364		1700	1800
4	14 98	337	4 500	3 826		1700	1800
5	20 78	375	5 563	4 813		1700	1800
6	28 57	432	6 625	5 761		1700	1800
8	43 39	500	8 625	7 625		1700	2400
10	54 74	500	10 750	9 750		1700	1900
12	65 42	500	12 750	11 750		1500	1900

B-EXTRA STRONG

T 45 COUNTERSINK ON SIZES 3½ AND SMALLER
30 COUNTERSINK ON SIZES 4 AND LARGER



Pipe: Nominal size	Pipe: Outside diameter D	Threads: Number per inch	Threads: Length from end of pipe to hand tight plane L_1	Threads: Effective length L_2	Threads: Total length end of pipe to vanish point L_4	Threads: Pitch diameter at hand tight plane E_1	Coupling: Outside diameter W	Coupling: Length N_1	Coupling: Length from face of coupling to hand tight plane M	Coupling: Width of bearing face R	Coupling: Hand tight stand off A
Ins	Ins		Ins	Ins	Ins	Ins	Ins	Ins	Ins	Ins	Thds
1/8	405	27	180	2638	3924	37476	563	13/16	0 56	Approximately thickness of coupling	4 23
1/4	540	18	200	4018	5916	48089	719	1 3/16	0833		5 60
3/8	675	18	240	4078	6000	62701	875	1 3/16	0833		4 99
1/2	840	14	320	5337	7815	77843	1 063	1 9/16	1071		4 96
3/4	1 050	14	339	5457	7935	98887	1 313	1 5/8	1071		4 86
1	1 315	11 1/2	400	6828	9845	1 23863	1 576	2	1304		5 22
1 1/4	1 660	11 1/2	420	7068	1 0085	1 58338	1 900	2 1/16	1304		5 27
1 1/2	1 900	11 1/2	420	7235	1 0252	1 82234	2 200	2 1/16	1304		5 16
2	2 375	11 1/2	436	7565	1 0582	2 29627	2 750	2 1/8	1304		5 66
2 1/2	2 875	8	682	1 1375	1 5712	2 76216	3 250	3 1/8	1875		5 61
3	3 500	8	766	1 2000	1 6337	3 38850	4 000	3 1/4	1875		5 43
3 1/2	4 000	8	821	1 2500	1 6837	3 88881	4 625	3 3/8	1875		5 40
4	4 500	8	844	1 3000	1 7337	4 38713	5 000	3 1/2	2500		5 12
5	5 563	8	937	1 4063	1 8400	5 44929	6 296	3 3/4	2500		5 22
6	6 625	8	958	1 5125	1 9462	6 50597	7 390	4	2500		5 91

C-COUPLINGS

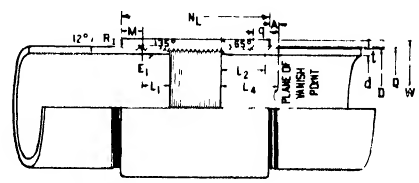
Reproduced From Nat Tube Co Gen Catalog 1945

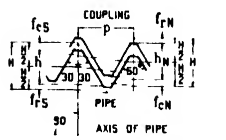
STANDARD PIPE

FIG 161

Size Nominal	Weight per foot: Nominal Threads and coupling	Weight per foot: Plain end	Pipe: Thickness	Pipe Diameters: Outside	Pipe Diameters: Inside	Threads per inch	Couplings: Length	Couplings: Outside diameter	Couplings: Weight	† Test pressure: Lap-welded or Grade A Seamless	Test pressure: Grade B Seamless	Test pressure: Grade C Seamless
Ins	Lbs	Lbs	Ins	Ins	Ins		Ins	Ins	Lbs	Lbs per sq in		
1/8	25	24	068	405	269	27	1 1/16	563	04	700	700	700
1/4	43	42	088	540	364	18	1 5/8	719	05	700	700	700
3/8	57	57	091	675	493	18	1 5/8	875	1	700	700	700
1/2	86	85	109	840	622	14	2 1/8	1 063	23	700	700	700
3/4	1 14	1 13	113	1 050	824	14	2 1/8	1 313	34	700	700	700
1	1 70	1 68	133	1 315	1 049	11 1/2	2 5/8	1 576	54	700	700	700
1 1/4	2 30	2 27	140	1 660	1 380	11 1/2	2 3/4	2 054	1 03	1000	1100	1300
1 1/2	2 75	2 72	145	1 900	1 610	11 1/2	2 3/4	2 200	50	1000	1100	1300
2	3 75	3 65	154	2 375	2 067	11 1/2	3 1/4	2 875	2 13	1000	1100	1300
2 1/2	5 90	5 79	203	2 875	2 469	8	4 1/8	375	3 7	1000	1100	1300
3	7 70	7 58	216	3 500	3 068	8	4 1/4	4 000	4 09	1000	1100	1300
3 1/2	9 25	9 11	226	4 000	3 548	8	4 3/8	4 625	92	1200	1300	1600
4	11 00	10 79	237	4 500	4 026	8	4 1/2	5 200	7 59	1200	1300	1600
5	15 00	14 62	258	5 563	5 047	8	4 5/8	6 296	9 98	1200	1300	1600
6	19 45	18 97	280	6 625	6 065	8	4 7/8	7 390	12 92	1200	1300	1600
8	25 55	24 70	277	8 625	8 071	8	5 1/4	9 625	23 18	1200	1300	1600
8	29 35	28 55	322	8 625	7 981	8	5 1/4	9 625	23 18	1200	1300	1600
10	32 75	31 20	279	10 750	10 192	8	5 3/4	11 750	31 5	1000	1200	1400
10	35 75	34 24	307	10 750	10 136	8	5 3/4	11 750	31 [illegible]	000	[illegible]	1400
10	41 85	40 48	365	10 750	10 020	8	5 3/4	11 750	31 55	1000	1[illegible]00	1400
12	45 45	43 77	330	12 750	12 090	8	6 1/8	14 000	49 27	1000	1200	1400
12	51 15	49 56	375	12 750	12 000	8	6 1/8	14 000	49 27	1000	1200	1400
14 D	57 00	54 57	375	14 000	13 250	8	6 3/8	15 000	45 83	950	1100	1400
15 D	61 15	58 57	375	15 000	14 250	8	6 5/8	16 000	51 26	900	1000	1400
16 D	65 30	62 58	375	16 000	15 250	8	6 3/4	17 000	55 83	850	1000	1300
17 D	73 20	69 70	393	17 000	16 214	8	7	18 000	61 07	850	950	1200
18 D	81 20	76 84	409	18 000	17 182	8	7 1/8	19 000	66 53	800	950	1200
20 D	90 00	85 58	409	20 000	19 182	8	7 5/8	21 000	79 37	750	850	1100

A-PIPE DETAILS





Thread Element	Number per inch: 27	18	14	11½	8
	Dimensions - Inches				
P =	.0370	.0556	.0714	.0870	.1250
H = .866 P	.0321	.0481	.0619	.0753	.1082
h = h_N = .760 P	.0281	.0422	.0543	.0661	.0950
f_{rS} = f_{rN} = .033 P	.0012	.0018	.0024	.0029	.0041
f_{cS} = f_{cN} = .073 P	.0027	.0041	.0052	.0063	.0091
Taper 1 in 16 on Diameter					

Pipe: Nominal size	Pipe: Outside diameter D	Threads: Number per inch	Threads: Length from end of pipe to hand tight plane L_1	Threads: Effective length L_2	Threads: Total length end of pipe to vanish point L_4	Threads: Pitch diameter at hand tight plane E_1	Coupling: Outside diameter W	Coupling: Length N_1	Coupling: Diameter of recess Q	Coupling: Depth of recess q	Coupling: Length from face of coupling to hand tight plane M	Coupling: Width of bearing face R	Coupling: Hand tight stand off A
Ins	Ins		In	Ins	In	In	Ins	In	Ins	In	Ins	Ins	Thds
1/8	405	27	180	2638	3924	37476	563	1 1/16	468	0317	1011	[illegible]	3
1/4	540	18	200	4018	5916	48089	719	1 5/8	603	1471	278	[illegible]	3
3/8	675	18	240	4078	6000	62701	875	1 5/8	738	1117	1038	[illegible]	3
1/2	840	14	320	5337	7815	77843	1 063	2 1/8	903	1582	1473	[illegible]	3
3/4	1 050	14	339	5457	7935	98887	1 313	2 1/8	1 113	1516	2103	[illegible]	3
1	1 315	11 1/2	400	6828	9845	1 23863	1 576	2 5/8	1 378	2211	3235	[illegible]	3
1 1/4	1 660	11 1/2	420	7068	1 0085	1 58338	2 054	2 3/4	1 723	2270	3275	[illegible]	3
1 1/2	1 900	11 1/2	420	7235	1 0252	1 82234	2 200	2 3/4	1 963	2439	3412	[illegible]	3
2	2 375	11 1/2	668	9881	1 2901	2 29627	2 875	3 1/4	2 469	2379	3611	[illegible]	2
2 1/2	2 875	8	682	1 1375	1 5712	2 76216	3 375	4 1/8	2 969	3015	6392	[illegible]	2
3	3 500	8	766	1 2000	1 6337	3 38850	4 000	4 1/4	3 593	4710	6177	[illegible]	2
3 1/2	4 000	8	821	1 2500	1 6837	3 88881	4 625	4 3/8	4 093	3662	6127	[illegible]	2
4	4 500	8	844	1 3000	1 7337	4 38713	5 000	4 1/2	4 593	1920	6397	[illegible]	2
5	5 563	8	937	1 4063	1 8400	5 44929	6 296	4 5/8	5 657	5017	6530	[illegible]	2
6	6 625	8	958	1 5125	1 9462	6 50597	7 390	4 7/8	6 719	5861	7382	[illegible]	2
8	8 625	8	1 063	1 712	2 1162	8 50003	9 625	5 1/4	8 719	6768	[illegible]	[illegible]	2
10	10 750	8	1 210	1 925	2 3387	10 62094	11 750	5 3/4	10 844	7391	8087	[illegible]	2
12	12 750	8	1 360	2 500	2 6837	12 61781	14 000	6 1/8	12 844	7872	9187	[illegible]	2
14 D	14 000	8	1 562	2 500	2 6837	13 87200	15 000	6 3/8	14 094	7136	8717	[illegible]	2
15 D	15 000	8	1 687	2 3500	2 7837	14 87119	16 000	6 5/8	15 094	6897	8367	[illegible]	2
16 D	16 000	8	1 812	2 3500	2 8837	15 87375	17 000	6 3/4	16 094	6658	8277	[illegible]	2
17 D	17 000	8	1 900	2 5500	2 9837	16 87[illegible]	18 000	7	17 094	6773	8377	[illegible]	2
18 D	18 000	8	2 000	2 6500	3 0837	17 87500	19 000	7 1/8	18 094	6773	8337	[illegible]	2
20 D	20 000	8	2 12	2 8500	3 2837	19 87031	21 000	7 5/8	20 094	7190	9087	3/8	2

B-COUPLINGS

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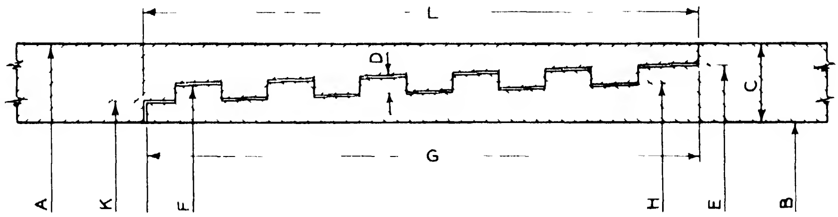
API STANDARD LINE PIPE

FIG 162

Strong Pipe of seamless steel tubing is generally used, but even then the casing with flush joints is not able to withstand repeated blows of a drop hammer as well as welded pipe with outside couplings



PIPE			JOINT			PIN			BOX		
Outside Diameter	Inside Diameter	Wall Thickness	Taper—Inches per Foot on the Diameter	No of Square Threads per Inch	Depth of Threads	O D Threads Base	O D Threads End	Length	I D Threads Top	I D Threads Bottom	Length
In	In	In			In	In	In	In	In	In	In
A	B	C			D	E	F	G	H	K	I
4 500	3 826	0 337	3/8	4	0 120	4 260	4 182	2 486	4 036	3 958	2 500
6 625	5 761	0 432	3/8	2	0 140	6 240	6 147	2 984	5 975	5 881	3 000
8 000	7 000	0 500	3/8	2	0 200	7 780	7 687	2 984	7 396	7 302	3 000

Waterways Experiment Station Vicksburg

EXAMPLE OF FLUSH JOINTED CASING

FIG 163

8.3 Special Types of Casing

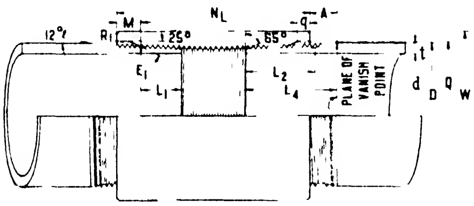
Several special types of pipe and couplings have been developed for use as casing for water wells and are occasionally also employed as casing in exploratory borings The Seamless Drive Pipe, Fig 164, is used for the so-called driven wells, that is, the pipe is driven into the soil far ahead of the boring and is provided with a drive and well point or cleaned out after the driving The pipe has the same dimensions as Standard Welded Pipe, but it is made of seamless steel tubing The couplings are so designed that the ends of the pipe butt against each other when the joint is fully made up. This joint is stronger during the driving than an open joint, in which the threads of the coupling must transmit the entire force caused by blows of a drop hammer On the other hand, the ends of pipe with butt joints may become upset or beaded after repeated use and may thereby obstruct the insertion or withdrawal of boring and sampling equipment It should be noted that the coupling, as well as the other couplings shown in Fig 161-168, is shown in a hand-tight, and not in a fully made up, position

The Boston Water Well Casing, Fig 165, is lighter than Standard Pipe and therefore not able to withstand heavy and repeated use It is occasionally employed as casing in exploratory borings when soil conditions are favorable and the boring is advanced far ahead of the casing

Many types of casing and couplings have been developed for use as casing in oil wells In regions where such casing is readily available, it is also used as

casing in shallow exploratory borings. Above the minimum external diameter of 4-1/2 in., oil well casing is available in a greater variety of diameters and wall thicknesses than Standard Pipe. Some of the principal types of oil well casing are

Size Nominal	Weight per foot: Nominal Threads and coupling	Weight per foot: Plain end	Pipe: Thickness	Pipe: Diameters Outside	Pipe: Diameters Inside	Coupling: Length	Coupling: Outside diameter	Coupling: Weight	Test pressure: Lap welded Grade A seamless	Test pressure: Grade C seamless
Ins	Lbs	Lb	Ins	Ins	Ins	Ins	Ins	Lbs	Lb per sq in	
6	19 4	18 97	280	6 625	6 065	5 1/8	7 390	13 35	1200	[illegible]
8	25 55	24 70	277	8 625	8 071	6 1/8	9 625	26 87	1200	1500
8	29 35	28 55	322	8 625	7 981	6 1/8	9 625	26 87	1200	1800
8	32 40	31 [illegible]	354	8 625	7 917	6 1/8	9 625	26 80	1200	2000
10	32 75	31 20	279	10 750	10 192	6 5/8	11 750	36 05	1000	[illegible]
10	35 7	34 24	307	10 750	10 136	6 5/8	11 750	36 0	1000	1100
10	41 85	40 18	365	10 750	10 020	6 5/8	11 750	36 05	1000	1600
12	45 15	43 77	330	12 750	12 090	6 5/8	14 000	52 72	1000	1200
12	51 15	49 56	375	12 750	12 000	6 5/8	14 000	52 72	1000	1400
14 D	57 00	54 57	375	14 000	13 250	7 1/8	15 000	50 22	900	1300
15 D	61 15	58 57	375	15 000	14 250	7 1/8	16 000	53 70	900	1200
16 D	65 30	62 58	375	16 000	15 250	7 1/8	17 000	57 17	850	1100



TAPER 1 IN 64 ON DIAMETER

Pipe: Nominal size	Pipe: Outside diameter D	Threads: Number per inch	Threads: Length from end of pipe to hand tight plane L_1	Threads: Effective length L_2	Threads: Total length end of pipe to vanish point L_4	Threads: Pitch diameter at hand tight plane E_1	Coupling: Outside diameter W	Coupling: Length N_L	Coupling: Diameter of recess Q	Coupling: Depth of recess q	Coupling: Length from face of coupling to hand tight plane M	Coupling: Width of bearing face R	Coupling: Hand tight stand off A
Ins	Ins		Ins	Ins	Ins	Ins	Ins	Ins	Ins	Ins	Ins	Ins	Thds
6	6 625	8	1 093	1 973	2 438	6 51375	7 390	5 1/8	6 719	3/8	595	1/4	6
8	8 625	8	1 593	2 473	2 938	8 51375	9 625	6 1/8	8 719	3/8	595	1/4	6
10	10 750	8	1 843	2 723	3 188	10 63875	11 750	6 5/8	10 844	3/8	595	3/8	6
12	12 750	8	1 843	2 723	3 188	12 63875	14 000	6 5/8	12 844	3/8	595	3/8	6
14 D	14 000	8	2 093	2 973	3 438	13 88875	15 000	7 1/8	14 094	3/8	595	3/8	6
15 D	15 000	8	2 093	2 973	3 438	14 88875	16 000	7 1/8	15 094	3/8	595	3/8	6
16 D	16 000	8	2 093	2 973	3 438	15 88875	17 000	7 1/8	16 094	3/8	595	3/8	6

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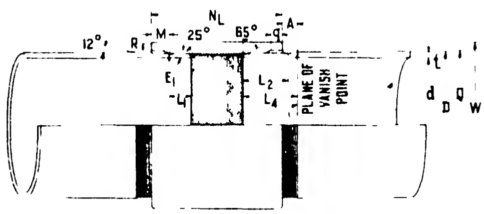
SEAMLESS DRIVE PIPE

FIG 164

Size outside diameter	Weight per foot: Nominal threads and coupling	Weight per foot: Plain end	Casing: Thickness	Casing: Diameter Outside	Casing: Diameter Inside	Threads per inch	Coupling: Length	Coupling: Outside diameter	Coupling: Weight	Test pressure: Lap welded or Grade A seamless
In	Lbs	Lbs	Ins	In	Ins		Ins	In	Lbs	Lbs per sq in
3 1/2	4 60	4 51	125	3 500	3 250	11	3 1/8	4 000	2 86	1100
4	5 65	5 53	134	4 000	3 73	14	3 1/8	4 500	3 21	1000
4 1/2	6 75	6 61	142	4 500	4 216	14	3 5/8	5 000	4 26	950
5 1/2	9 00	8 79	154	5 500	5 192	14	4 1/8	6 050	6 38	850
6	10 50	10 24	164	6 000	5 672	14	4 1/8	6 625	7 81	850
6 5/8	13 00	12 72	18	6 62	6 255	11 1/2	4 5/8	7 390	11 88	850
8 5/8	17 50	16 90	188	8 62	8 219	11 1/2	5 1/8	9 375	16 92	650



TAPER 1 IN 32 ON DIAMETER

Size outside diameter D	Thread: Number per inch	Thread: Length from end of pipe to hand tight plane L_1	Thread: Effective length L_2	Thread: Total length end of pipe to vanish point L_4	Thread: Pitch diameter at hand tight plane E_1	Coupling: Outside diameter W	Coupling: Length N_L	Coupling: Diameter of recess Q	Coupling: Depth of recess q	Coupling: Length from face of coupling to hand tight plane M	Coupling: Width of bearing face R	Coupling: Hand tight stand off A
In		Ins	In	Ins	Ins	Ins	Ins	Ins	Ins	Ins	Ins	Thd
3 1/2	14	5241	1 0455	1 3071	3 4296	4 000	3 1/8	3 19/32	1/4	426	[illegible]	5
4	14	5741	1 0955	1 3571	3 9296	4 500	3 1/8	4 3/32	1/4	426	[illegible]	5
4 1/2	14	6241	1 1455	1 4071	4 4296	5 000	3 5/8	4 19/32	1/4	426	[illegible]	5
5 1/2	14	7241	1 2455	1 5071	5 4296	6 050	4 1/8	5 19/32	1/4	426	[illegible]	5
6	14	7741	1 2955	1 5571	5 9296	6 625	4 1/8	6 3/32	1/4	426	[illegible]	5
6 5/8	11 1/2	9123	1 3783	1 6973	6 5445	7 390	4 5/8	6 3/32	1/4	437	3/16	4
8 5/8	11 1/2	1 1123	1 5783	1 8973	8 5445	9 375	5 1/8	8 3/32	1/4	437	3/16	4

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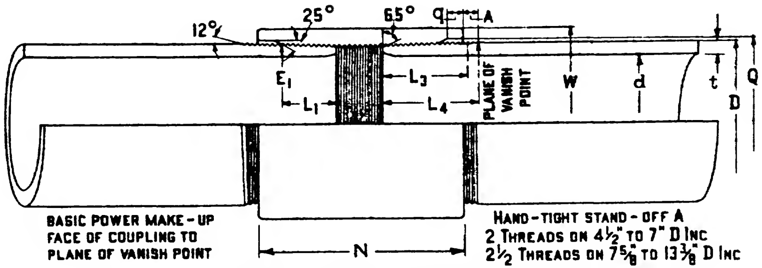
BOSTON WATER WELL CASING

FIG 165

shown in Fig 166-168, but the dimensions are given only for a few selected sizes which approximately correspond to those of Standard Pipe. It should be noted that this casing is designated by its external diameter and weight per linear foot, whereas Standard Pipe and Drive Pipe are designated by the approximate internal diameter.

8.4 Diamond Core Drill Casing and Drill Rods

Special casing and drill rods have been developed for use in diamond core



JOINT SHOWN HAND-TIGHT—8 ROUND THREADS PER INCH—TAPER 1 IN 16 ON DIA

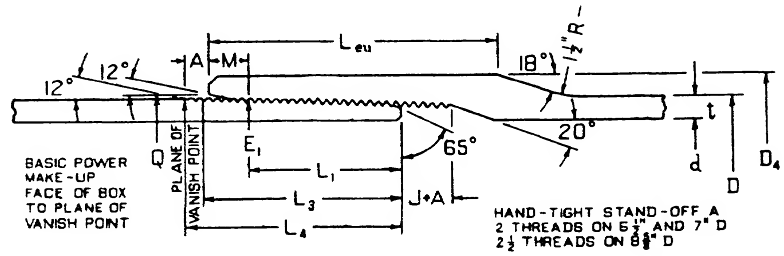
PIPE				Nominal Weight in Lb per Ft	COUPLING		SHORT COUPLING				LONG COUPLING			
Nom Size Outside Diam	Wall Thickness	Inside Diameter	Drift Diameter		Outside Diameter	Pitch Diam at Hand tight Plane	Total Length	Length to Hand tight Plane	Effective Length	Length to Vanish Point	Total Length	Length to Hand tight Plane	Effective Length	Length to Vanish Point
D	t	d			W	E_1	N	I_1	I_2	I_4	N	L_1	L_2	L_4
In	In	In	In		In	In	In	In	In	In	In	In	In	In
4½	0 205	4 090	3 965	9 50	5 000	4 412	5	1 055	1 715	2 000				
4½	0 290	3 920	3 795	13 50	5 000	4 412	5	1 055	1 715	2 000	7	2 055	2 715	3 000
5	0 220	4 560	4 435	11 50	5 563	4 912	6½	1 555	2 215	2 500				
5	0 362	4 276	4 151	18 00	5 563	4 912	6½	1 805	2 465	2 750	7¾	2 430	3 090	3 375
5½	0 228	5 044	4 919	13 00	6 050	5 412	6¾	1 680	2 340	2 625				
5½	0 415	4 670	4 545	23 00	6 050	5 412	6¾	1 930	2 590	2 875	8	2 555	3 215	3 500
6	0 238	5 524	5 399	15 00	6 625	5 912	7	2 055	2 715	3 000				
6	0 380	5 240	5 115	23 00	6 625	5 912	7	2 055	2 715	3 000	8½	2 805	3 465	3 750
6⅝	0 245	6 135	6 010	17 00	7 390	6 537	7¼	2 180	2 840	3 125				
6⅝	0 475	5 675	5 550	32 00	7 390	6 537	7¼	2 180	2 840	3 125	8¾	2 930	3 590	3 875
7	0 231	6 538	6 413	17 00	7 656	6 912	7¼	1 430	2 090	2 375				
7	0 540	5 920	5 795	38 00	7 656	6 912	7¼	2 180	2 840	3 125	9	3 055	3 715	4 000
7⅝	0 250	7 125	7 000	20 00	8 500	7 533	7½	1 863	2 590	2 875				
7⅝	0 500	6 625	6 500	39 00	8 500	7 533	7½	2 238	2 965	3 250	9¼	3 113	3 840	4 125
8⅝	0 264	8 097	7 972	24 00	9 625	8 533	7¾	1 988	2 715	3 000				
8⅝	0 557	7 511	7 386	49 00	9 625	8 533	7¾	2 363	3 090	3 375	10	3 488	4 215	4 500
9⅝	0 281	9 063	8 907	29 30	10 625	9 533	7¾	2 238	2 965	3 250				
9⅝	0 545	8 535	8 379	53 50	10 625	9 533	7¾	2 363	3 090	3 375	10½	3 738	4 465	4 750
10¾	0 279	10 192	10 036	32 75	11 750	10 658	8	1 738	2 465	2 750				
10¾	0 495	9 760	9 604	55 50	11 750	10 658	8	2 488	3 215	3 500	10½	3 738	4 465	4 750

Only min and max wall thickness shown in this table Sizes 11¾ 13⅜ 16 and 20 inches not shown Casing also available with light and heavy internal upset at joints

Based on National Tube Company Supplement to Oil Country Tubular Products Handbook 1945

A P I STANDARD CASING

FIG 166



DISTANCE END OF PIPE TO COUNTER BORE MADE UP J=0 500

JOINT SHOWN HAND TIGHT—8 ROUND THREADS PER IN —TAPER 1 IN 16 ON DIA

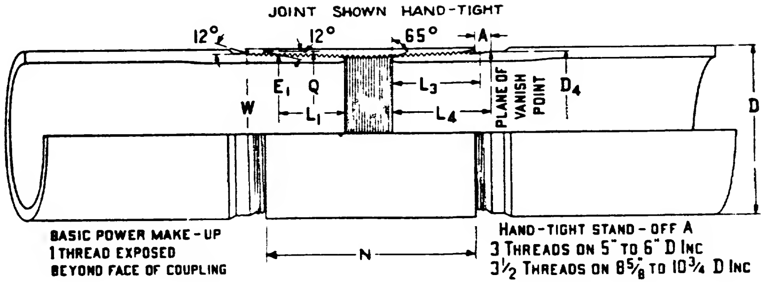
PIPE				Nominal Weight in Lb per Ft	BOX				PIPE AND THREADS			
Nom Size Outside Diam	Wall Thickness	Inside Diameter	Drift Diameter		Outside Diameter	Diameter of Recess	Total Length	Length to Hand-tight Plane	Pitch Diameter	Length to Hand-tight Plane	Effective Length	Length to Vanish Point
D	t	d			D_4	Q	L_{eu}	M	E_1	L_1	L_2	L_4
In	In	In	In		In	In	In	In	In.	In	In	In
5½	0 244	5 012	4 887	14 00	6 050	5⅝	4 250	0 695	5 412	2 180	2 840	3 125
5½	0 275	4 950	4 825	15 50								
5½	0 304	4 892	4 767	17 00								
5½	0 361	4 778	4 653	20 00								
5½	0 415	4 670	4 545	23 00								
7	0 272	6 456	6 331	20 00	7 656	7⅛	4 500	0 695	6 912	2 430	3 090	3 375
7	0 317	6 366	6 241	23 00								
7	0 362	6 276	6 151	26 00								
7	0 408	6 184	6 059	29 00								
7	0 453	6 094	5 969	32 00								
7	0 498	6 004	5 879	35 00								
8⅝	0 304	8 017	7 892	28 00	9 438	8¾	4 750	0 700	8 533	2 613	3 340	3 625
8⅝	0 352	7 921	7 796	32 00								
8⅝	0 400	7 825	7 700	36 00								
8⅝	0 450	7 725	7 600	40 00								
8⅝	0 500	7 625	7 500	44 00								
8⅝	0 557	7 511	7 386	49 00								

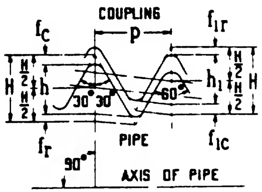
This casing is also furnished with a light or heavy internal upset

Based on Jones and Laughlin Steel Corporation Bulletin O C 5 1945

INTEGRAL JOINT CASING

FIG 167





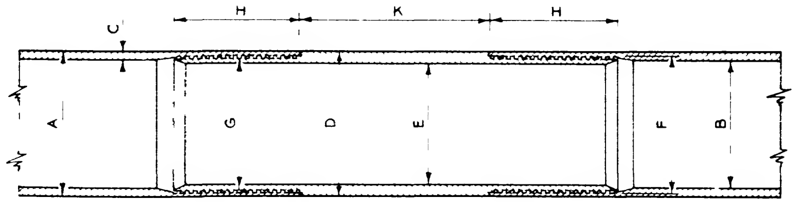
THREAD DATA	
THREAD ELEMENT	NUMBER PER INCH
	8
	DIMENSIONS - INCHES
P =	12500
H = 866P	10825
h = h1 = 626P − 007	07125
fr = fir = 120P + 002	01700
fc = fic = 120P + 005	02000
TAPER 1 IN 16 ON DIAMETER	

PIPE						COUPLING				THREADS			
Nom Size Outside Diam	Wall Thickness	Inside Diameter	Inside Diam At Upset	Drift Diameter	Nominal Weight in Lb per Ft	Turn Down Diameter	Outside Diameter	Diameter of Recess	Total Length	Pitch Diam at Hand tight Plane	Length to Hand tight Plane	Effective Length	Length to Vanish Point
D	t	d	d_{iu}			D_4	W	Q	N	E_1	L_1	L_3	L_4
In	In	In	In	In		In	In	In	In	In	In	In	In
5	0 296	4 408	4 181	4 151	15 00	4 750	5 000	4 404	6¼	4 662	1 805	2 465	2 750
5½	0 304	4 892	4 683	4 653	17 00	5 250	5 500	5 404	6½	5 162	1 [illegible]	2 540	2 875
6	0 288	5 424	5 257	5 227	18 00	5 750	6 000	5 904	6¾	5 662	2 055	2 715	3 000
8⅝	0 400	7 825	7 680	7 600	36 00	8 313	8 625	8 465	7½	8 221	2 363	3 000	3 375
9⅝	0 352	8 921	8 719	8 679	36 00	9 345	9 625	9 497	7½	9 253	2 363	3 000	3 375
9⅝	0 395	8 835	8 719	8 679	40 00	9 345	9 625	9 497	7½	9 253	2 363	3 000	3 375
10¾	0 400	9 950	9 834	9 794	45 50	10 438	10 750	10 590	7¾	10 346	2 488	3 215	3 500
10¾	0 450	9 850	9 644	9 604	51 00	10 438	10 750	10 590	7¾	10 346	2 488	3 215	3 500

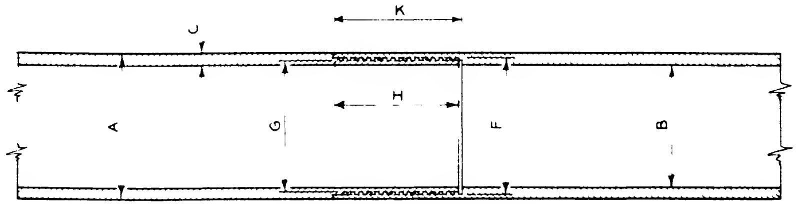
Based on National Tube Company Supplement to Oil Country Tubular Products Handbook 1945

SEAMLESS CASING WITH FLUSH COUPLINGS

FIG 168



FLUSH COUPLED CASING



FLUSH JOINTED CASING

	SIZE DESIGNATION			EX	AX	BX	NX
Flush Coupled Casing	O D Casing	A	In	1 813	2 250	2 875	3 500
	I D Casing	B	In	1 625	2 000	2 469	3 063
	Wall Thickness	C	In	0 094	0 125	0 203	0 219
	O D Coupling	D	In	1 813	2 250	2 875	3 500
	I D Coupling	E	In	1 500	1 906	2 375	3 000
	O D Thread	F	In	1 720	2 127	2 689	3 314
	I D Thread	G	In	1 653	2 059	2 590	3 215
	Length Pin	H	In	1 750	2 000	2 125	2 375
	Length Grip	K	In	1 500	3 000	3 500	3 500
	Length Coupling	J	In	5 000	7 000	7 750	8 250
Threads	8 Square Threads per Inch			5°			5°
Flush Joint Casing	O D Casing	A	In	1 813	2 250	From CS 17-42 Eliminated in CS 17-47	
	I D Casing	B	In	1 495	1 901		
	Wall Thickness	C	In	0 159	0 175		
	O D Thread	F	In	1 718	2 125		
	I D Thread	G	In	1 654	2 060		
	Length of Pin	H	In	1 750	2 000		
	Length of Box	K	In	1 815	2 065		

The dimensions shown in this table are averages For further details on tolerances clearances for threads etc see CS 17 47

STANDARD DIAMOND CORE DRILL CASING

FIG 169

drilling operations and have been standardized in four sizes by the **Diamond Core Drill Manufacturers Association** and the **National Bureau of Standards (156).** The casing and its couplings are so designed that the loss in hole diameter is a minimum, when a given size of casing cannot be advanced further and it becomes necessary to use a smaller and nesting string of casing during continued advance of the bore hole The four standard sizes of Diamond Core Drill Casing, Fig 169, are designated as the corresponding standard sizes of drill rods and coring bits, see Fig. 261 and Table 10 NX coring bits, operated with N drill rods, will pass through NX casing and drill a hole large enough to admit BX casing, which in turn will admit BX coring bits, drilling a hole large enough for AX casing, etc Some manufacturers furnish flush-jointed in addition to the standard flush-coupled casing and also casing with 4-1/2-in OD and 3-15/16-in ID , but the latter size has not yet been standardized Standard Pipe, Fig. 161, or casing standardized by the **American Petroleum Institute** and called A P I casing, Fig 166, is generally used in diamond core borings exceeding the NX size

Whereas the above mentioned casing is used almost exclusively in diamond core boring, the corresponding drill rods, Fig 170, are also used extensively in all types of subsurface exploration and soil sampling Flush-jointed instead of flush-coupled drill rods can be obtained from some manufacturers

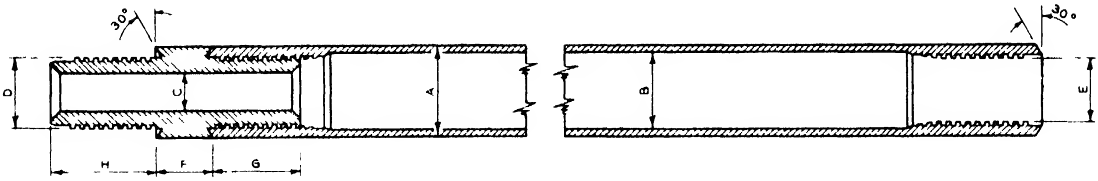
8.5 Special Drill Rods and Couplings

The size N diamond core drill rods are also manufactured with special couplings in addition to the standard coupling, and a heavier drill rod, generally designated PK but R by some manufacturers, has been introduced, Fig 171 These special couplings and the heavier drill rods have not yet been standardized, and there are minor differences in the thread design used by various manufacturers, but the over-all dimensions are nearly identical The special NX and PK drill rods are used extensively with the motorized drilling rigs of the type shown in Fig 38 In addition to these special drill rods, some manufacturers furnish drill rods of the same general design as the Standard Diamond Core Drill Rods in sizes down to 1-in OD with 3/4-in ID and up to 3-7/16-in OD with 3-1/16-in ID

The Calyx Core Drill Rods, Fig 172, are primarily used for operating small shot core barrels, whereas A P.I. Drill Pipe, Fig 173, is used with the larger core barrels

8.6 Standard A.P.I. Drill Pipe and Tool Joints

The drill rods and special couplings or joints used in rotary drilling for oil have to a large extent been standardized by the **American Petroleum Institute** (A P.I.) These drill rods are also used in exploratory borings for civil engineering purposes, and nearly all rotary drilling bits and many core barrels have standard A P.I boxes and pins, but "subs" or bushings for connection to other types of drill



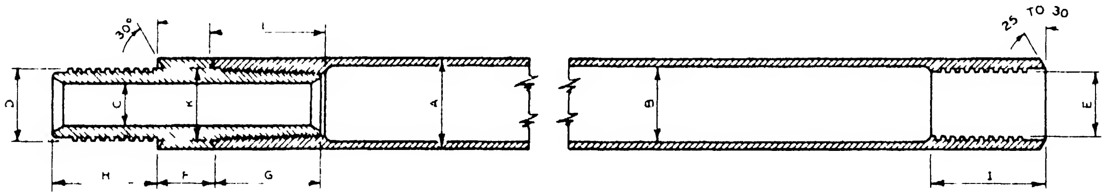
SIZE DESIGNATION			E	A	B	N	PK*
O D Rod	In	A	1 313	1 625	1 906	2 375	2 875
I D Rod	In	B	0 844	1 266	1 406	2 000	2 313
I D Coupling	In	C	0 438	0 563	0 625	1 000	1 250
Sq Threads per Inch			3	3	5	4	2
O D Thread	In	D	1 002	1 267	1 408	1 877	2 315
I D Thread	In	L	0 872	1 137	1 277	1 683	2 108
Length of Grip	In	F	1 500	1 500	1 500	1 500	4 000
Length of Joint	In	G	1 500	1 750	1 875	2 375	4 500
Length of Pin	In	H	1 500	1 750	1 875	2 750	4 500

The dimensions shown are averages for details clearances for threads and tolerances see Commercial Standard CS 17 47

* PK rods are not included in Standard but furnished by most manufacturers, and there are minor differences in thread designs—modified square and modified Acme threads

STANDARD DIAMOND CORE DRILL RODS

FIG 170

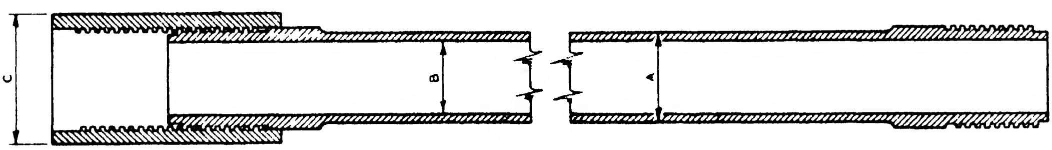


SIZE			N	PK	SIZE			N	PK
O D Rod	In	A	2 375	2 875	Length Box	In	I	3 000	4 000
I D Rod	In	B	2 000	2 313	Length Grip	In	F	1 500	4 000
I D Coupling	In	C	1 125	1 188	Pipe Threads per Inch			11½	8
Square Threads per Inch			4	2	Taper In /Ft on diam			¾	¾
O D Thread	In	D	1 877	2 313	Diam Base Pin	In	K	1 875	2 313
I D Thread	In.	E	1 680	2 119	Length Pin	In	G	2 750	4 000
Length Pin	In	H	2 750	4 500	Length Box	In	L	3 000	4 750

Based on data furnished by Sullivan Machinery Company

SPECIAL DIAMOND CORE DRILL RODS

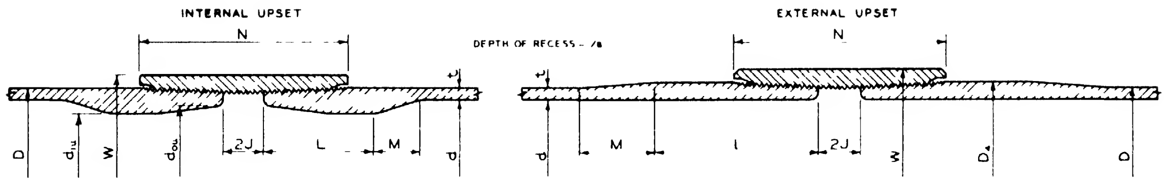
FIG 171



SIZE DESIGNATION				G	F	M
Drill Rod	Outside Diam.	In.	A	1 313	1 875	2 375
	Inside Diam.	In.	B	0 938	1 500	1 938
	Weight Lb /Ft.			2 4	4 0	6 0
Coupling	Outside Diam.	In.	C	2 000	2 750	3 375
	Weight	Lb./Ft.		1 6	3 5	6 0

CALYX CORE DRILL RODS

FIG 172



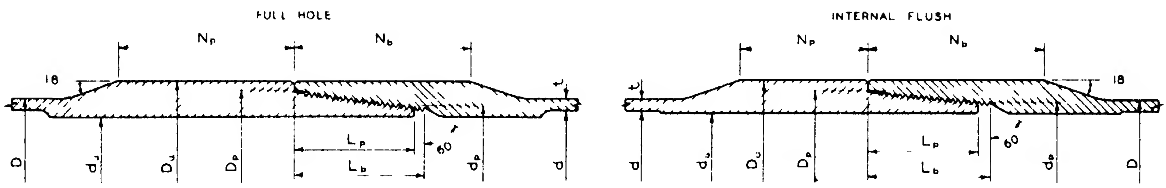
8 A P I ROUND THREAD PER INCH TAPER 1 IN 16 ON THE DIAMETER — HAND TIGHT STAND OFF 3 THREADS — DISTANCE BETWEEN ENDS OF PIPE MADE UP

PIPE			Nominal Weight	INTERNAL UPSET					Length Coupling	EXTERNAL UPSET			
Nom Size O D	Wall	I D		I D End	I D Min	Length Upset Min	Length Taper	O D Coupl		O D Coupl	O D Upset	Length Upset Av	Length Taper
D	t	d	Lb /Ft	d_{ou}	d_{iu}	L	M	W	N	W	D_4	L	M
In	In	In		In	In	In	In	In	In	In	In	In	In
2⅜	0 280	1 815	6 65	1⅜	1⅛	3¼	1½	3 125	5½	3 375	2 656	4 625	2½
2⅞	0 362	2 151	10 40	1 9/16	1 3/16	3½	1½	3 750	6½	4 125	3 219	5,125	2½
3½	0 368	2 764	13 30	2⅜	1⅞	3½	1½	4 250	6½	4 625	3 824	5 125	2½
3½	0 449	2 602	15 50	2¼	1¾	3½	1½	4 250	6½	4 625	3 824	5 125	2½
*4½	0 337	3 826	16 60	3 1/32	2 13/16	5	2	5 500	8	6 000	5 000	5 875	2½
4½	0 430	3 640	20 00	3 1/32	2 13/16	5	2	5 500	8	6 000	5 000	5 875	2½
5 9/16	0 352	4 859	22 20	4 1/32	3 13/16	5	2	6 750	8½	7 375	6 063	6 125	2½
5 9/16	0 415	4 733	25 25	3⅞	3½	5	2	6 750	8½	7 375	6 063	6 125	2½
6⅝	0 330	5 965	25 20	5 11/32	5	5	2	7 750	9	8 500	7 125	6 375	2½

*Tentative A P I Standard—For further details see for example Jones and Laughlin Steel Corp Bul O C -5 1945 or Nat Tube Co Oil Country Tubular Products Supplement, 1945

A P I STANDARD DRILL PIPE

FIG 173

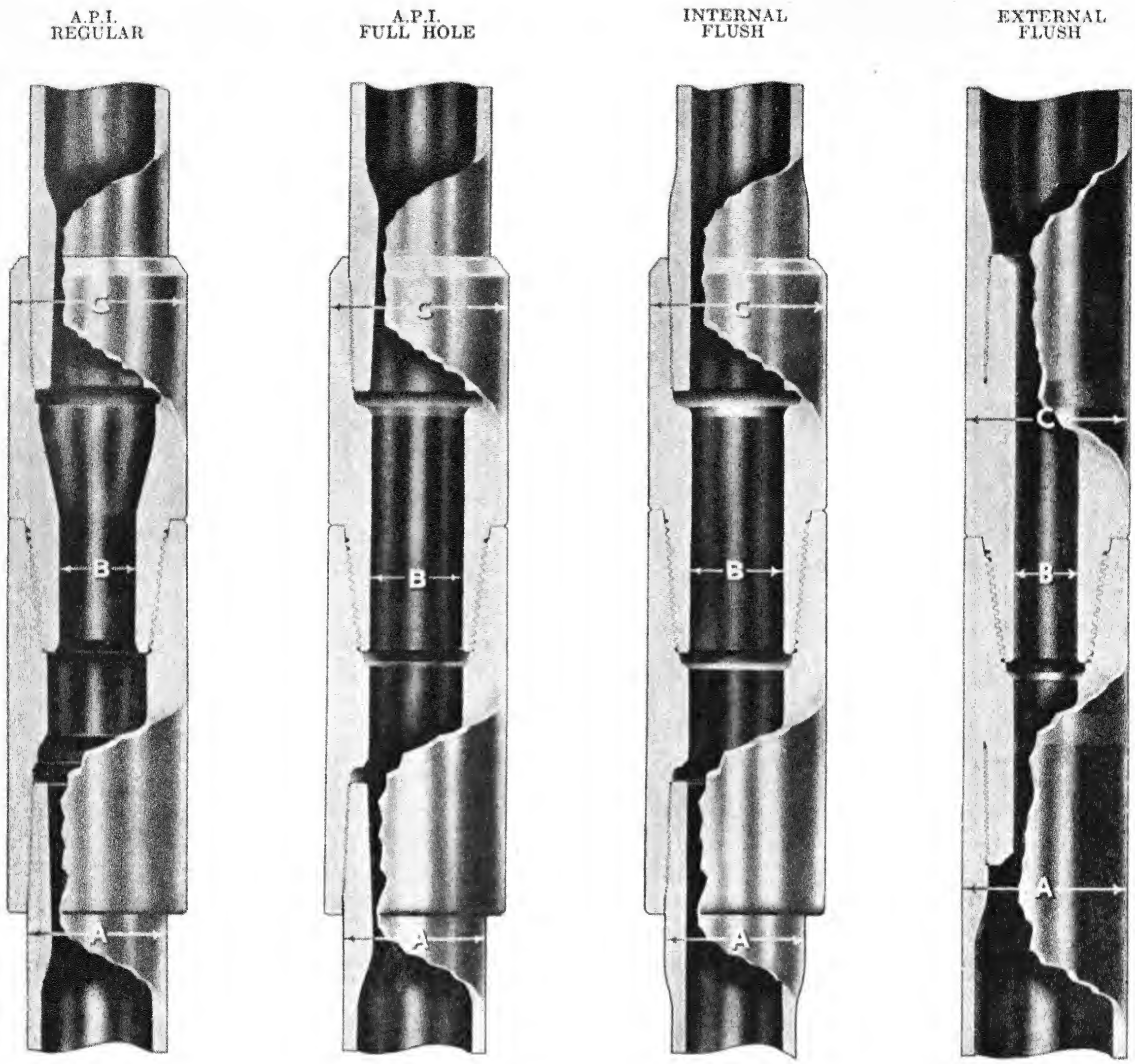


TYPE	PIPE			Nominal Weight	DIAM UPSET		LENGTH UPSET		LENGTH JOINT		DIAM PIN		V-Flat Threads per inch	Taper on Diam.
	Nom Size O D	Wall	I D		O D	I D	Pin	Box	Pin	Box	Base	End		
	D	t	d	Lb /Ft	D_u	d_u	N_p	N_b	L_p	L_b	D_p	d_p		
	In	In	In		In	In	In	In	In	In	In	In		
FULL HOLE	3½	0 368	2 764	13 40	4 625	2 438	5 5	5 5	3 75	4 063	3 994	3 056	5	1 in 4
	4½	0 337	3 826	17 20	5 750	3 156	6 5	6 5	4 00	4 313	4 792	3 792	5	1 in 4
	4½	0 430	3 640	21 80	5 750	3 156	6 5	6 5	4 00	4 313	4 792	3 792	5	1 in 4
	5 9/16	0 375	4 813	24 00	7 000	4 000	7 0	7 0	5 00	5 375	5 825	4 992	4	1 in 5
	5 9/16	0 415	4 733	26 20	7 000	4 000	7 0	7 0	5 00	5 375	5 825	4 992	4	1 in 5
	6⅝	0 375	5 875	29 20	8 000	5 000	7 0	7 0	5 00	5 375	6 753	5 920	4	1 in 5
	6⅝	0 432	5 761	32 50	8 000	5 000	7 0	7 0	5 00	5 375	6 753	5 920	4	1 in 5
INT FLUSH	2⅞	0 362	2 151	10 45	4 125	2 125	4 0	5 5	3 50	3 875	3 391	2 808	4	1 in 5
	3½	0 368	2 764	13 45	4 750	2 688	5 5	5 5	4 00	4 375	4 016	3 349	4	1 in 5
	4½	0 337	3 826	17 25	6 125	3 750	6 5	6 5	4 50	4 875	5 250	4 500	4	1 in 5
	4½	0 430	3 640	22 05	6 125	3 750	6 5	6 5	4 50	4 875	5 250	4 500	4	1 in 5

For further details see Jones & Laughlin Steel Corp Bulletin O C -5, 1945

INTEGRAL JOINT DRILL PIPE

FIG 174



TYPE		A. P. I. REGULAR								A. P. I. FULL HOLE			
SIZE O. D. PIPE		2 3/8	2 7/8	3 1/2	4 1/2	5 9/16	6 5/8	7 5/8	8 5/8	3 1/2	4 1/2	5 9/16	6 5/8
O. D. Upset	A	2.375	2.875	3.500	4.500	5.563	6.625	7.625	8.625	3.500	4.500	5.563	6.625
I. D. Joint (Max.)	B	1.000	1.250	1.500	2.250	2.750	3.500	4.000	4.750	2.438	3.156	4.000	5.000
O. D. Joint	C	3.125	3.750	4.250	5.500	6.750	7.750	9.000	10.00	4.625	5.750	7.000	8.000
Length of Joint		16	17	18	20	22	24	26	28	18	20	22	24
O. D. Pin Base		2.625	3.000	3.500	4.625	5.519	5.992	7.000	7.951	3.994	4.792	5.825	6.753
Taper in./ft. on diam.		3	3	3	3	3	2	3	3	3	3	2	2
Threads per inch		5	5	5	5	4	4	4	4	5	5	4	4

TYPE		INTERNAL FLUSH						EXTERNAL FLUSH					
SIZE O. D. PIPE		2 3/8	2 7/8	3 1/2	4 1/2	5 9/16	6 5/8	2 3/8	2 7/8	3 1/2	4 1/2	5 9/16	6 5/8
O. D. Upset	A	2.656	3.218	3.824	5.000	6.062	7.125	2.375	2.875	3.500	4.500	5.563	6.625
I. D. Joint	B	1.750	2.125	2.688	3.750	4.813	5.906	0.875	0.875	1.250	1.750	2.500	3.000
O. D. Joint	C	3.375	4.125	4.750	6.125	7.375	8.500	2.375	2.875	3.531	4.531	5.563	6.625
Length of Joint		16	17	18	20	22	24	15.25	16.50	17.50	17.75	20.00	23.50

Figures and dimensions from Catalogue No. 15, Hughes Tool Co.

EXAMPLES OF DRILL PIPE WITH TOOL JOINTS

FIG. 175

rods are readily available

The principal dimensions of the A P.I. Drill Pipe are shown in Fig 173 It will be observed that the outside and inside diameters, but not the couplings, of the two smaller sizes of this drill pipe are identical with those of the N and PK drill rods mentioned in the foregoing section When used in deep borings, the drill pipe is generally furnished with special taper thread joints, called tool joints, in order to facilitate the coupling and uncoupling of a long string of pipe Examples of such tool joints are shown in Fig 175 The taper of the threads in the Regular A P I. Tool Joint is 3 in per foot, measured on the diameter The joints are designated by the outside diameters of the threads at the base and at the end of the pin

When wire line core barrels are used, Section 14 3, the Regular Tool Joints are replaced with Full Hole Tool Joints, in which the internal diameter of the pin is equal to the internal diameter of the upset end of the regular drill pipe Internal Flush Tool Joints are also used, but they require externally upset drill pipe, and the taper of the pins in the joints is then generally reduced to 2 in per foot, measured on the diameter In recent years the drill pipe is often furnished with integral tool joints, that is, the tool joint box and pin sections are welded to the drill pipe The principal dimensions of "Full Hole" and "Internal Flush" Integral Joint Drill Pipe are shown in Fig 174

CHAPTER 9
OPEN DRIVE SAMPLERS

9.1 General

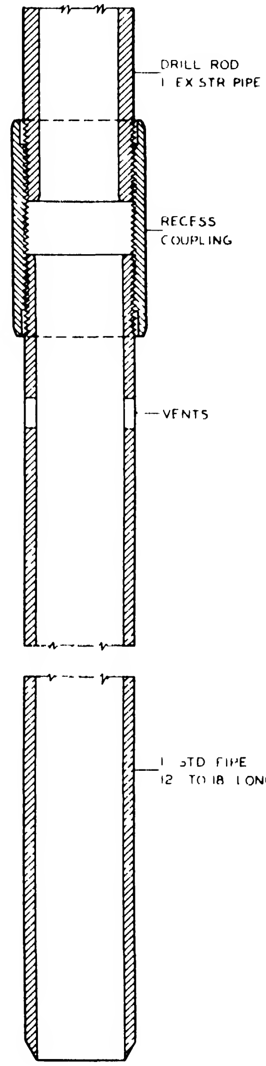
Reference is made to Sections 4 11, 4 13 and 4 14 for a discussion of the requirements for and the general principles of construction and operation of open drive samplers The principal advantage of these samplers is their simplicity in both construction and operation They are therefore preferred by the drillers and are used extensively in reconnaissance explorations, but these samplers also have several serious disadvantages, which particularly must be borne in mind when undisturbed samples are desired These disadvantages are (1) that disturbed soil from the sides and bottom of the bore hole may enter the sampler and often causes the upper part of the sample to be completely disturbed and non-representative; (2) that soil displaced by the walls of the sampler or its shoe may be forced into the sampler as excess soil and cause serious disturbance of the soil structure, (3) that considerable excess hydrostatic pressure often is created over the sample, hindering the entrance of soil and decreasing the length of sample which can be obtained in a single operation, and (4) that it is difficult to determine the initial penetration and, consequently, the total penetration and recovery ratio with sufficient accuracy

9.2 Thick-Wall Open Drive Samplers

Although this part of the report primarily deals with equipment for obtaining undisturbed samples, several thick-wall samplers will also be described, since it may be necessary to use such samplers in hard and very dense or coarse-grained soils However, it is emphasized that thick-wall open drive samplers principally are suited for obtaining representative but partially disturbed samples

The simplest form of an open drive sampler consists of a section of Standard Pipe with a sharpened cutting edge, Fig 176 The use of such a sampler for obtaining so-called "dry samples" during wash borings was introduced in this country by **Charles Gow**, and the reliability of this type of boring in determining the soil profile has been greatly increased thereby The sample is removed from the pipe by pushing, rodding, or tapping, and it is generally seriously disturbed

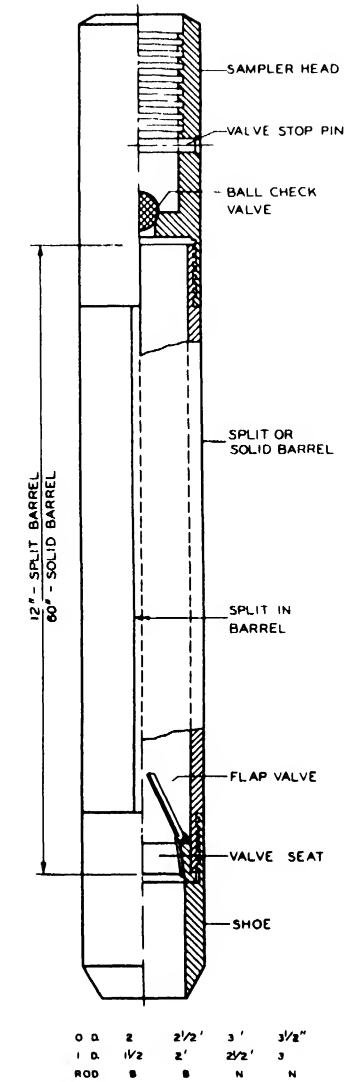
The efficiency of the simple pipe sampler can be increased by furnishing it with a detachable shoe with a hardened cutting edge and inside clearance and, at the other end, with a special sampler head containing a check valve The removal of the sample is facilitated and the disturbance of the soil during this operation decreased by use of a barrel which is split longitudinally into halves which are held together by the shoe and sampler head. After withdrawal, the shoe and sampler head and one-half of the split barrel are removed, thereby exposing the sample The split barrel sampler shown in Fig 177 was developed by **Sprague & Henwood Inc.(174, 175)** and the one shown in Fig 178 by the **Raymond Concrete Pile Co. (166).** These samplers are used extensively in reconnaissance surveys, and the penetration resistance is usually determined, see correlation of penetration resistance and soil properties in Table 6, Section 4 10 The split barrel has relatively little rigidity and can be used only for short samplers It is replaced with a solid-wall barrel for long samplers and in sampling of very compact soils, such as glacial till, in which it may be expedient to advance the bore hole by continuous sampling, see Section 2 17



GOW PIPE SAMPLER

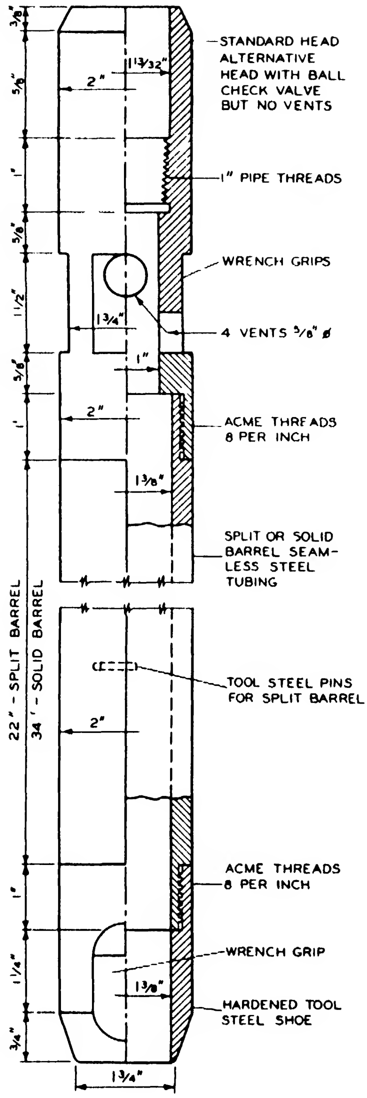
FIG 176

Thick-wall samplers are nearly always forced into the soil by repeated blows of a hammer, and they therefore attain, momentarily, considerable downward velocities When they are operated under water, very large hydrostatic pressures may be created over the sample, especially since the vents and check valves usually are relatively small Large excess hydrostatic pressures over the sample not only hinder the entrance of soil into the sampler but may also increase by several fold the number of blows required to drive the sampler a given distance into the soil The proposed heavy duty sampler, shown in Fig 179, therefore has three large vents, so arranged that the water will not have to flow around the check valve The outside diameter of the shoe has been increased so that it provides an outside clearance of four to five percent This outside clearance will decrease the penetration resistance of the sampler in many cohesive soils, but it will increase this resistance when the sampler is used in cohesionless soils An alternate shoe without outside clearance should therefore be provided The single flap valve in the sampler shown in Fig 177 greatly obstructs the entrance of soil, and it is suggested that it be replaced with multiple valves similar to those shown in Fig 238, 239, 241, or 287 The sampler shown in Fig 179 is a solid-wall sampler, but the same principles can, of course, also be used for a split barrel sampler



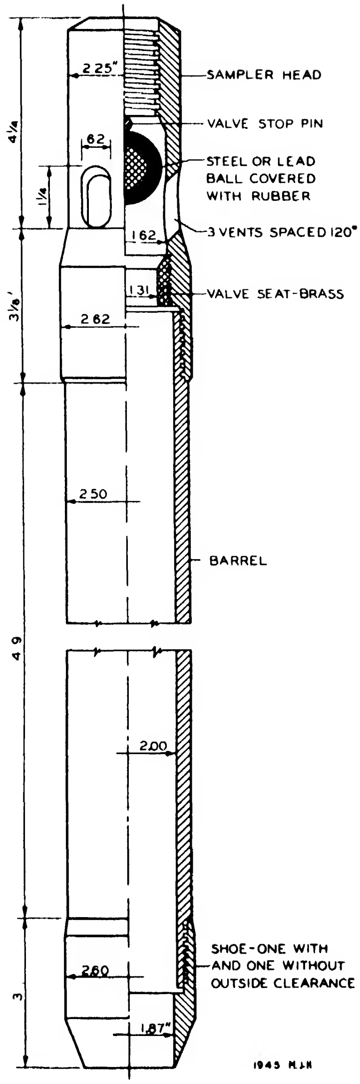
SPRAGUE & HENWOOD SAMPLER

FIG 177



RAYMOND SAMPLER

FIG 178



PROPOSED HEAVY DUTY SAMPLER

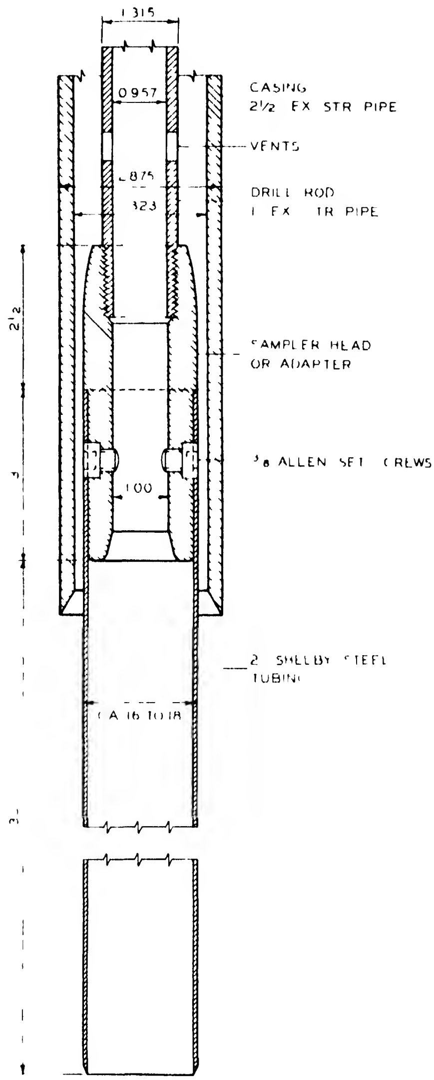
FIG 179

9.3 Thin-Wall Open Drive Samplers

A thin-wall or "Shelby Tubing" sampler was introduced in 1936 by **H. A. Mohr (341)** in order to comply with a request from **A. Casagrande** for obtaining, within the standard 2-1/2-in. casing, larger and less disturbed samples than those taken with the heavy-wall samplers described in the foregoing section. The thin-wall sampler, Fig. 180, consists of a section of Shelby Tubing which is fastened to an adapter or sampler head by means of two set screws The corresponding holes in the tubing are drilled slightly oversize, so that a downward force on the drill rod is transmitted directly to the tubing through the shoulder on the adapter, whereas

a pull on the drill rod is transmitted to the tubing through the set screws.

The term "Shelby Tubing" is a trade name for hard-drawn, seamless steel tubing, manufactured by the National Tube Company, but any other type of thin-wall steel or brass tubing of comparable hardness and strength may be used Therefore, in this report the original name "Shelby Tubing Sampler" is changed to "Thin-Wall Sampler"



SHELBY TUBING SAMPLER BY H A MOHR

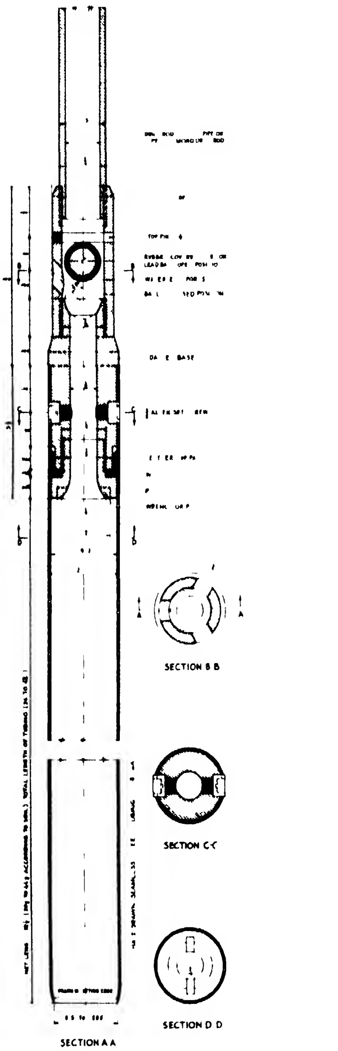
FIG 180

The actual sampling procedure with a thin-wall sampler is the same as with other open drive samplers, Section 4 14 The sample may be removed in the field from short samplers, but long samples are sealed and shipped in the tubing When it is desired to examine and test the sample, the tubing is first cut into sections with a length of three to six times its diameter in order to facilitate the removal of the sample, see Chapter 16.

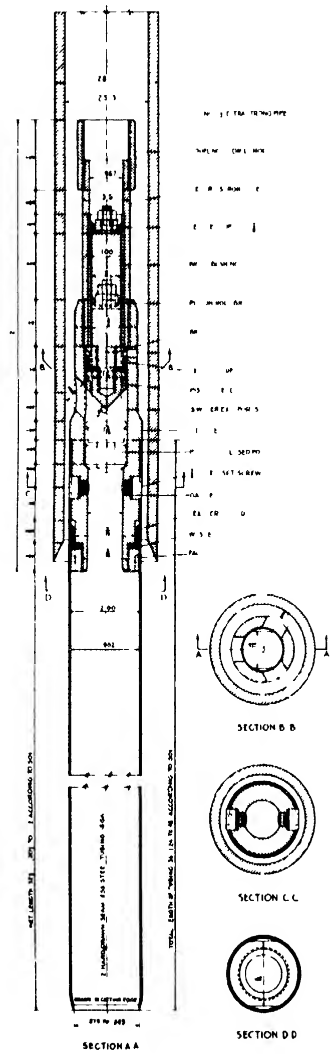
An improved design of a 2-in thin-wall sampler is shown in Fig 181 It has large vents, a ball check valve, and leather cup packing at the lower end of the adapter This packing prevents leakage between the tubing and the adapter, which otherwise might render the check valve ineffective A ball check valve is easily fouled by soil grains, and the piston type check valve shown in Fig. 182 is more reliable Before lowering the sampler, the piston check valve is pushed up into the sampler head and is held there by the friction between the brass bushing and the leather packing at the top of the short piston rod After the sampler has been forced into the soil, the piston check valve is forced down to its lower position by hydrostatic pressure, obtained by connecting the drill rod to the pump It should be noted that the packing at the piston valve and the short piston rod permits leakage in an upward but not in a downward direction. A similar sampler for 3-1/2-in tubing but with a slightly different sampler head is shown in Fig. 183 The 3-1/2-in tubing is the maximum size which can be used within a casing of 4-1/2-in. Extra Strong Pipe.

Thin-wall samplers have been designed and built in Europe concurrently with and independently of their development in this country A medium-thin-wall sampler, Fig. 186, was developed by the Building Research Station in England and

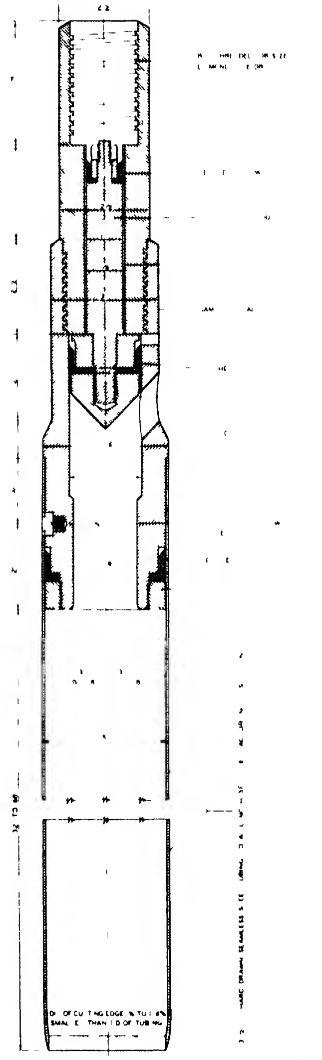
has been described by **Cooling and Smith (311)**. The tubing is relatively short, and samples are removed from it in the field and preserved in special containers. To facilitate removal of the sample, the tubing is split into halves which are held to-



2" THIN-WALL SAMPLER
WITH BALL CHECK VALVE
FIG 181



2" THIN-WALL SAMPLER
WITH PISTON CHECK VALVE
FIG 182

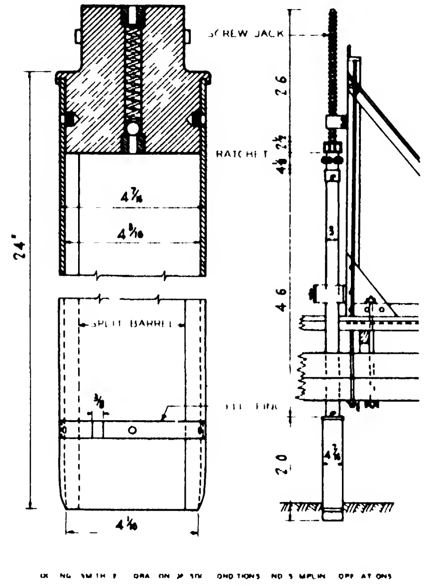


3½" THIN-WALL SAMPLER
WITH PISTON CHECK VALVE
FIG 183

gether by a collar in the sampler head and by a split ring near the cutting edge. This sampler is primarily used for sampling near the ground surface, and it is forced into the soil by means of a screw jack and ratchet arrangement

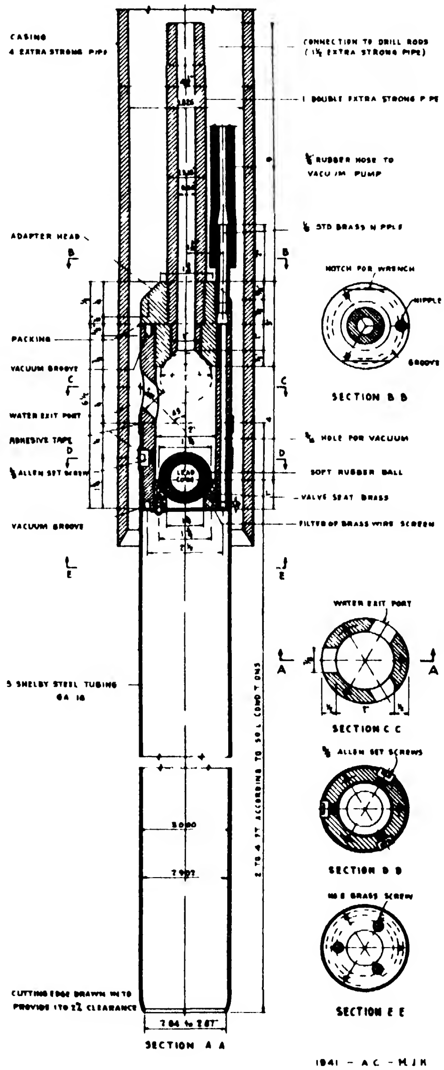
L. Casagrande (106) reports that a thin-wall sampler with a diameter of about 8 in and with a bevelled and drawn-in cutting edge has been built and used successfully in foundation explorations near Hamburg, Germany. The sampler has

been used in bore holes with depths up to 400 ft, from which 40-in long samples of very stiff plastic clays were obtained. The zone of visible distortions of the soil layers was about 1/8 in deep.



4" THIN-WALL SPLIT BARREL SAMPLER
FIG 186

Experiments by the Committee on Sampling and Testing have demonstrated that a thin-wall sampler causes much less disturbance of the soil than a sampler with thick walls. This conclusion has been verified by extensive use of thin-wall samplers in recent years The thin-wall sampler is especially well suited for use in detailed explorations where long and fairly continuous samples of relatively small diameter are desired, but it is not strong enough for use in hard, very dense or coarse-grained, or in partially cemented soils, and in sampling of soft soils it should be provided with a stationary piston Even in fairly stiff soils it will generally be found advantageous to use a sampler with a free or stationary piston instead of an open sampler



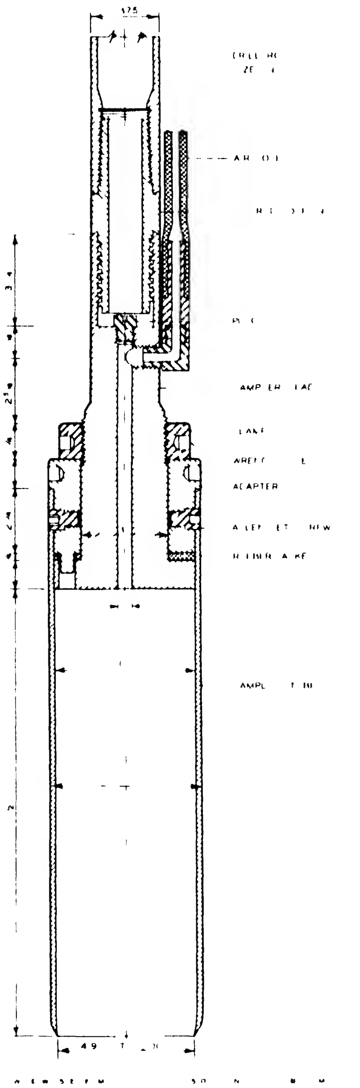
3" THIN-WALL SAMPLER
WITH VACUUM CONNECTION
FIG 184

9.4 Thin-Wall Samplers with Air Connections

As indicated in the foregoing section, the tightness of a ball check valve is easily impaired by soil grains, and the effectiveness of even a piston type check valve may be decreased by upward seepage of water through samples of porous soils. The effect of such a leakage or seepage may be eliminated by connecting the sampler head to a vacuum pump at the ground surface and thereby maintaining a partial vacuum over the sample during withdrawal.

A thin-wall sampler, designed in accordance with the above mentioned principle at the suggestion of **A. Casagrande**, is

shown in Fig. 184 The connections from the vacuum pump lead to an annular groove at the bottom of the sampler head, and this groove as well as the opening in the check valve seat is covered with fine wire mesh The maintenance of a partial vacuum over the sample will cause a constant upward flow of water through the sample to take place. This flow will decrease the danger of losing the sample, but it may also cause partial liquefaction, piping, and serious disturbance of the soil unless the top of the sample is in contact with and supported by a filter screen When used in cohesionless soils, it is therefore necessary to overdrive this sampler slightly in order to be certain that the top of the sample is in contact with the filter screen Fven then there is danger, as proved by later experiments, that a strong upward flow of water may cause internal erosion of the soil and remove some of its finer-grained constituents This sampler has been used successfully in cohesive soils but has not been subjected to decisive tests in cohesionless soils



5" VICKSBURG THIN-WALL SAMPLER
FIG 185

Two of the disadvantages of an open drive sampler -- the entrance of sludge or soft and disturbed soil at the bottom of the bore hole into the sampler, and the formation of large excess hydrostatic pressures over the sample during the actual sampling -- can be partially eliminated by connecting the sampler to an air pump or to a tank with compressed air and forcing the water and sludge out of the sampler just before it is seated at the bottom of the bore hole After the sampler has been forced a short distance into the soil, the valve to the compressed air supply is closed and another valve opened so that atmospheric pressure is maintained over the sample during the actual sampling operation

This principle of operation, first suggested by **Fernau (123)**, has been used by the **Vicksburg District** and the **Waterways Experiment Station,** Corps of Engineers, in the design of the sampler shown in Fig 185 The tubing is, as in previously described thin-wall samplers, fastened to the adapter by means of set screws, but leakage between the tubing and the adapter is in this case prevented by means of a rubber gasket which expands when the adapter is pressed against it by tightening the screw clamp The air pump is of the reversible type which can be used both to furnish compressed air and to produce a partial vacuum over the sample A small steel container is inserted in the hose connection near the

pump and serves to equalize pressure variations and to trap water and sediment which may be drawn up through the hose

The effective length of this sampler is short, since the sample is removed from the tubing in the field and placed in a larger cardboard container and encased in paraffin, see Fig 329C This method has the advantage that the entire sample can be inspected in the field and that it permits repeated use of the tubing However, encasing of the sample in paraffin is often time-consuming and difficult to perform in warm weather, and removal and handling of the unprotected sample under adverse field conditions may cause serious disturbance of the soil Furthermore, the top and bottom sections of the sample will usually be partially disturbed, Section 6 9, so that only a small section of a short sample can be considered as undisturbed

The above described type of sampler and method of operation have definite advantages over the simple, open drive sampler when it is used in cohesive soils of medium to stiff consistency However, excessive reduction of the pressure over the sample may cause serious disturbance of samples of soft or cohesionless soils, and it is difficult to formulate and apply rules for the amount of pressure reduction which can be used safely

9.5 Required Dimensions of Thin-Wall Tubing

The wall thickness of the tubing should be the minimum which will prevent damage to and serious deformation of the tubing during sampling A small wall thickness will not only cause less displacement of soil and reduce the penetration resistance of the sampler and the disturbance of the sample, but it will also facilitate the cutting of the tubing into short sections, preparatory to the removal of the samples from the tubing

Steel tubing with a wall thickness of 0 049 in , or 18 gage, has been found satisfactory for use in average soils when the diameter of the tubing is 2 to 3 in. A wall thickness of 0 035 in , or 20 gage, may be used in soft or loose soils Very stiff or dense soils and/or tubing with a diameter of 4 to 6 in may require a wall thickness of 0 065 in., or 16 gage Hard-drawn brass tubing will usually be satisfactory when used in somewhat softer soils than indicated for steel tubing, but it is more easily damaged when obstacles are encountered In sampling at depths greater than 100 to 150 ft it may be necessary to use a greater wall thickness, especially for brass tubing, since the withdrawal generally creates a partial vacuum below and in the lower part of the tubing, and the pressure of the surrounding soil may then cause collapse of the tubing.

The net length of the tubing, measured from the bottom of the adapter to the cutting edge, should be 2 to 4 in. longer than the desired gross length of the sample. This extra length of tubing serves as a reservoir for sludge and completely disturbed soil and as insurance against overdriving in case of minor errors in determining the total penetration of the sampler. The safe penetration, or maximum

length of sample which can be obtained with approximately 100 percent recovery ratio, varies with the diameter of the tubing and the character of the soil For 2-in. tubing with an inside clearance at the cutting edge of 0 7 to 1.5 percent, the safe depth of penetration was found to be 15 to 20 in. in sand and 30 to 42 in. in clayey silts and common clays of medium consistency Longer samples may be obtained in certain clays and, in general, when the inside clearance is increased and when a sampler with stationary piston is used

A length of tubing suitable for the average soil conditions in a given region or for the area under investigation may be adopted as standard, say 36 to 48 in. total length for 2-in. diameter tubing, but the actual penetration should be governed by the recoveries obtained during the sampling Sections of both shorter and longer tubing should also be on hand in order to avoid waste of tubing in sampling of dense or stiff soils and to expedite continuous sampling by taking longer samples when soil conditions are favorable.

The length of the tubing should be increased over the figures given above when the diameter is greater than 2 in , since the ratio between the safe length and diameter of the sample is approximately constant for a given type of sampler and soil, although this ratio seems to decrease slightly with the diameter However, it is often found expedient to limit the length of the sample to 5 ft, since both the drill rods and the casing generally are furnished in lengths of 5 or 10 ft

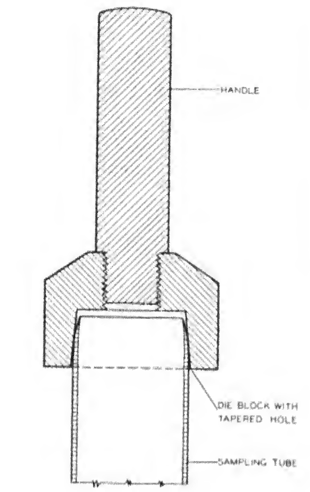
9.6 Cutting Edges on Thin-Wall Tubing

It is important that the tubing be provided with a sharp cutting edge with a positive inside clearance An inside clearance ratio of 0.7 to 1 5 percent is tentatively suggested for average conditions, but for best results the clearance should be adjusted to the soil conditions encountered Samplers of small diameter should be given a larger inside clearance than those of large diameter in order to compensate for the commercial tolerance on the inside diameter of the tubing Complete elimination of the inside clearance will decrease appreciably the maximum length of sample obtainable in a single operation, whereas an excessive clearance may cause loss of the sample during the withdrawal or slumping of samples of soft or cohesionless soils

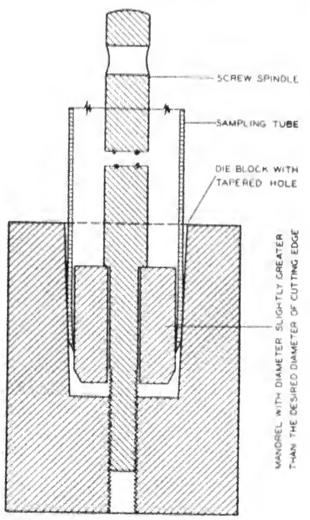
Two methods for producing a sharp cutting edge with a positive inside clearance have been developed One method consists in first bevelling and sharpening the end of the tubing, whereupon the inside clearance is produced by forcing a tapered sleeve or die down over the end of the tubing for a predetermined distance, Fig 187A The elastic expansion of the tubing after removal of the die block must be taken into consideration in determining this distance A closer control of the diameter of the cutting edge is obtained by first producing an excessive inside clearance and then reducing it to the desired value by forcing a mandrel of given diameter through the tubing, Fig 187B The diameter of the mandrel should be slightly

larger than the desired diameter of the cutting edge in order to compensate for the elastic contraction of the tubing after removal of the mandrel These methods were developed by the **Waterways Experiment Station (113)** and the **Providence District (120)**, Corps of Engineers.

A second method was developed during the research for the **Committee on**



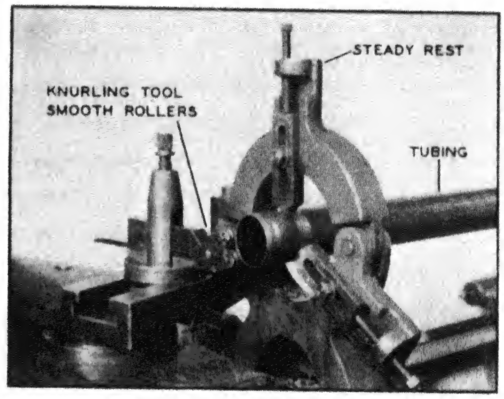
A - VICKSBURG METHOD



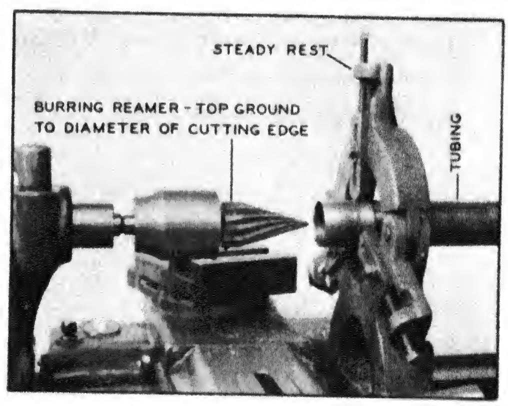
B - PROVIDENCE METHOD

DIE-BLOCK AND MANDREL METHOD

FIG 187



A - SPINNING THE EDGE OF THE TUBING IN



B - REAMING THE SPUN-IN EDGE TO REQUIRED DIAMETER

C - FINISHED CUTTING EDGE

SPINNING AND REAMING METHOD

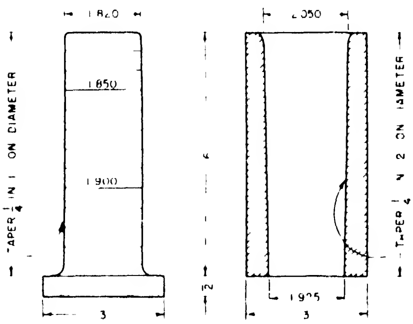
FIG 188

Sampling and Testing and with the cooperation of the **Waterways Experiment Station** and **Mr. Philip Grotjohan,** in charge of the machine shop of the Graduate School of Engineering, Harvard University The method consists in first spinning the edge of the tubing in, Fig 188A, and thereafter reaming it out to the desired diameter by means of a spiral fluted shell ream or burring reamer, which has been ground to the

desired diameter of the cutting edge, Fig 188B This method produces a stronger cutting edge with a diameter and inside clearance closer to that desired than can be obtained by the first mentioned method

Difficulties may be encountered in spinning-in the edge of the tubing unless the correct procedure is followed In general, the best results are obtained when the tubing is rotated at a speed of 200 to 300 revolutions per minute The feed and pressure of the spinning tool -- for example, a knurling tool with smooth rollers -- should be the maximum possible without producing undue ovality of the tubing. Work hardening may occur when the feed is too slow, and it may then be necessary to heat the end of the tubing by means of a blow torch in order to finish the job A spinning tool with two rollers, Fig 188A, is preferable for very thin walls, whereas a single roller often gives better results with heavier tubing The steady rest should be as close as possible to the end of the tubing in order to reduce bending and ovality When the wall thickness is very small and the diameter of the tubing large, it may be necessary to provide additional support during the spinning by placing a tight fitting wood plug in the lower end of the tubing

The inside clearance and thereby the diameter of the cutting edge is for practical reasons determined for the nominal or average internal diameter of the tubing The actual inside clearance will then vary between certain limits which are governed by the commercial tolerance on the inside diameter In the field it may be found desirable to increase or decrease the inside clearance of the sampling tubes in stock Such changes can be made by means of the clearance control equipment shown in Fig 189 The tapered mandrel is calibrated so that it can be used not only for increasing the diameter and decreasing the clearance, but also for measuring the inside diameter of the cutting edge and of the upper end of the tubing and thereby for determination of the actual inside clearance The tapered sleeve is used for decreasing the diameter of the cutting edge and for protection of the calibration marks on the mandrel when the equipment is not in use



CALIBRATED MANDREL TAPERED SLEEVE

CLEARANCE CONTROL EQUIPMENT

FIG 189

Replacement of the integral cutting edge with a detachable shoe of hardened steel has been considered, but the principal difficulty lies in finding a satisfactory method of fastening such a shoe to the tubing without causing either an excessive decrease in strength or an undesirable increase in area ratio of the sampler Bayonet locks, snap rings, short pins, and shallow threads have been suggested, but it is not known whether such connections always will be strong enough to retain the shoe when the sampler is rotated and withdrawn. It is doubtful that a satisfactory joint, except by welding, can be developed for tubing with a wall thickness of less than 0 065 in It is also questionable, at least

for tubing with a diameter less than 3 in., that the required machining to make the connection to the shoe will be cheaper than the preparation of an integral cutting edge.

9.7 Cleaning and Lacquering of the Tubing

Before assembling a thin-wall sampler, the tubing should be thoroughly cleaned. It is also advisable to pass a rag, soaked in oil or a rust preventive with an oil base, through the tubing after the cleaning, but all excess oil should be wiped off. A thick coating of oil or grease will not provide additional reduction of the friction or protection against corrosion since most of it will be removed when the soil enters the sampler, and it may enter the pores of the upper and outer part of the sample when the soil is porous and only partially saturated.

Samples preserved in untreated steel tubing for more than a few days or weeks will often show traces of rust, which not only may change the properties of the soil in the affected areas but make it difficult to remove the sample from the tubing without serious disturbance of the soil There is much less danger of corrosion when brass tubing is used, but corrosion may occur, even then, when samples are preserved in the tubing for several months, especially when there are air spaces between the sample and the tubing

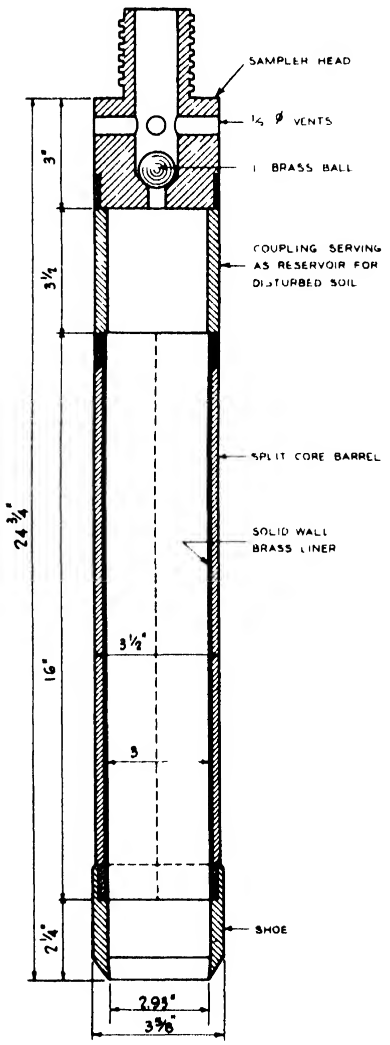
The **Waterways Experiment Station** has recently used modern rust preventives in treating steel sampling tubes and liners and with apparently good results, but it is not yet known whether these materials are able to prevent corrosion during protracted storage of samples in steel containers

Galvanizing the tubing will reduce the danger of corrosion, but the coating is relatively soft and likely to be damaged when the soil contains coarse and angular grains Experiments have been made with asphalt coating of thin-wall sampling tubes and liners, but this coating is not sufficiently hard, and it often adheres more strongly to the sample than to the tubing

Much better results were obtained in experiments with lacquering of the tubing, carried out by the **Boston Office** of the **Raymond Concrete Pile Company.** The tubing was first thoroughly cleaned and then dipped in the lacquer and allowed to dry after the surplus lacquer had drained off Such a lacquer coating reduced the penetration resistance of the sampler to a marked degree, the recovery ratios were increased, and it was much easier to remove the sample from the tubing in the laboratory. Only in a very few cases were signs of corrosion of the tubing and peeling of the lacquer observed, even after a storage of several months These defects may have been caused by improper cleaning before lacquering It is highly desirable that further experiments be made in order to determine the type of lacquer which will furnish the smoothest and toughest coating and the best protection against corrosion and chemical changes of the soil during protracted storage of the sample.

9.8 Review of Simple Composite Samplers

This section is primarily a review of composite open drive samplers which were in use in 1940. Since that time, research and further developments have primarily been concentrated on thin-wall samplers and piston samplers on account of the decided advantages of these samplers in obtaining undisturbed samples. This review is presented in order to demonstrate the development of soil samplers in this country and abroad, because some of the samplers were used in the experiments described in Part I of this report, and to call attention to certain details which may be used again and to other details which have been found wanting and should be avoided The review includes only fairly simple, composite drive samplers; other samplers of this type but with special arrangements for retaining samples of soft or cohesionless soils are described in Chapter 11. Some of the composite piston samplers, described in the following section, can also be used as open drive samplers when the piston is removed or replaced with a check valve



GEORGE L FREEMAN SOIL SURVEY FLUSHING MEADOW PARK SITE PROC FOUNDATION CONFERENCE 1936 VOL I

3" MORAN & PROCTOR SAMPLER
FIG 190

Liners -- Moran and Proctor sampler.- Nearly all early drive samplers for obtaining undisturbed samples consisted of a relatively short and heavy barrel with a detachable shoe and cutting edge The sample was pushed out of the barrel in the field and encased in paraffin or transferred to special containers. It was realized that this method often caused serious disturbance of samples of soft or cohesionless soils. Liners were then placed in the sampler barrel and were removed with and served to protect the sample during its shipment and storage Liners were first used in special samplers for obtaining samples of the bottom sediments of oceans and lakes. Liners for samplers used in foundation exploration were developed concurrently in Europe and in this country.

The first drive sampler with a liner, used in this country, was designed by **Beatty (514)** in accordance with instructions from the firm **Moran and Proctor.** The sampler was further developed by this firm, and a design described by **Freeman (322)** is shown in Fig. 190. The barrel is split into halves to facilitate the insertion and removal of the liner. Another innovation is the provision of a reservoir above the liner for sludge and disturbed soil. This sampler has been

used extensively, both by the firm originating it and by other organizations However, the vent and check valve are now considered too small and the walls of the barrel and shoe too heavy for obtaining undisturbed samples of soft soils or loose cohesionless soils, and the sampler has been replaced with thin-wall samplers or piston samplers.

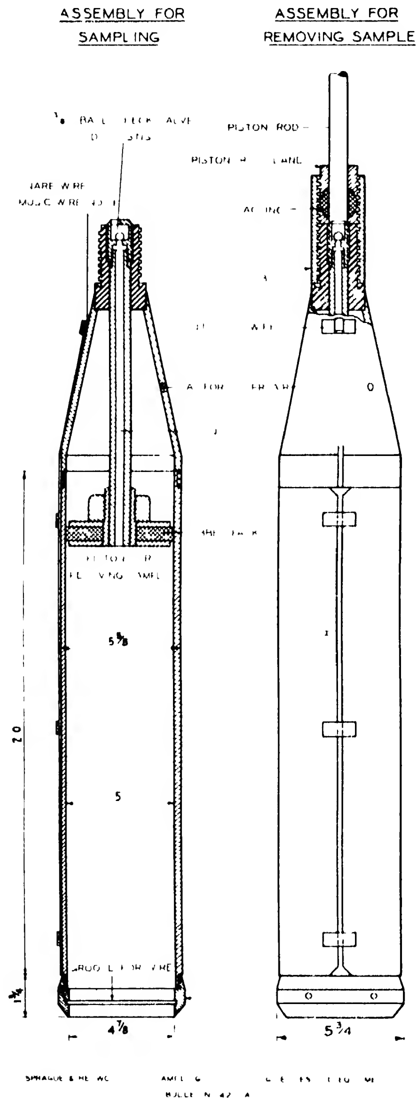
Cutting wire -- M.I.T. sampler.- When using the samplers described in the foregoing paragraph and sections, the sample must be separated from the subsoil by rotation or a direct pull This method often fails when the diameter of the sample is large, the soil is tough, and the inside friction small or the length of the sample relatively short In order to eliminate this cause of loss of samples, **A. Casagrande** suggested that the sample be cut free from the subsoil by means of a wire loop, which is placed in a groove in the sampler shoe A sampler embodying this idea was developed in cooperation with **Gilboy and Buchanan (305, 905)** and is commonly known as the M I T sampler To facilitate pushing the sample out of the barrel, the **Sprague & Henwood Co.** added a piston which can be operated by compressed air or by pushing on the short piston rod extension, Fig 191

The cutting wire groove in the shoe has three small entrance holes, spaced 120 degrees apart The cutting wire, gage 9 to 12 music wire, is bent double and a rope is attached to its center The ends of the wire are passed through one of the holes to the groove in the shoe, kinked and bent into two overlapping loops, sprung into the groove, and finally carried out through the other two holes and knotted or fastened by means of screws. The rope attached to the center of the wire is pulled up a little and the wire loops thereby straightened out just before the withdrawal of the sampler This method has the disadvantage that the cutting force of the wire decreases as the loops are straightened out and that, since the wire remains in the sampler, it is not known whether the cutting has been successfully completed Furthermore, the straightened wire will cut the sample lengthwise if any downward movement of the sample takes place during the withdrawal.

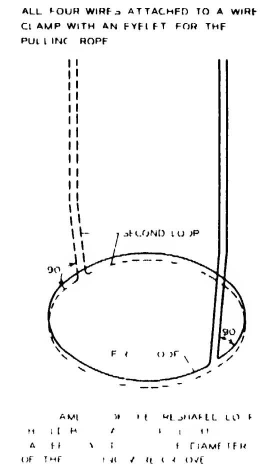
A simpler and better method of placing the cutting wire in the groove has been suggested by **H. A. Mohr (341)** and is shown in Fig. 192. A circular loop with a diameter slightly larger than that of the groove is formed in the center of the wire. This loop is sprung into the groove, and the two ends of the wire are passed out through one of the entrance holes and up through the guide groove or brackets on the barrel, and a few inches above the sampler head they are fastened to a clamp attached to the pulling rope Below this clamp the wires are taped lightly to the drill rod in order to keep them straight and avoid fouling during the lowering and driving of the sampler As insurance against slipping or breaking of the wire, a second cutting wire may be placed in a similar manner and attached to the single pulling rope. The cutting wire or wires are pulled free of the sampler and out of the bore hole before the start of the withdrawal.

Sampler shoes.- The original shoe for the M.I.T. sampler was short and its angle of taper very large This rather blunt cutting edge promotes entrance of

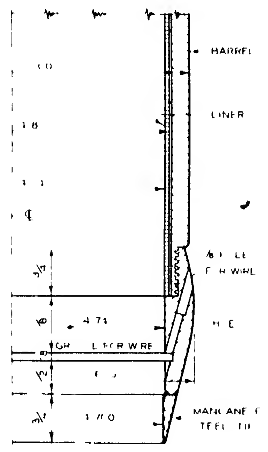
excess soil and disturbance of the sample, and the **Providence District,** Corps of Engineers, later replaced the short shoe with the more streamlined one shown in Fig 193 In addition, the sampler was provided with a liner. Experiments demonstrated that the streamlined shoe eliminated entrance of excess soil when sampling close to the ground surface, Fig 106B, but not during sampling at considerable depth, however, a further decrease of the angle of taper and also of the area ratio is possible



5" M I T SAMPLER
FIG 191



FORMING AND PLACEMENT OF CUTTING WIRES
FIG 192



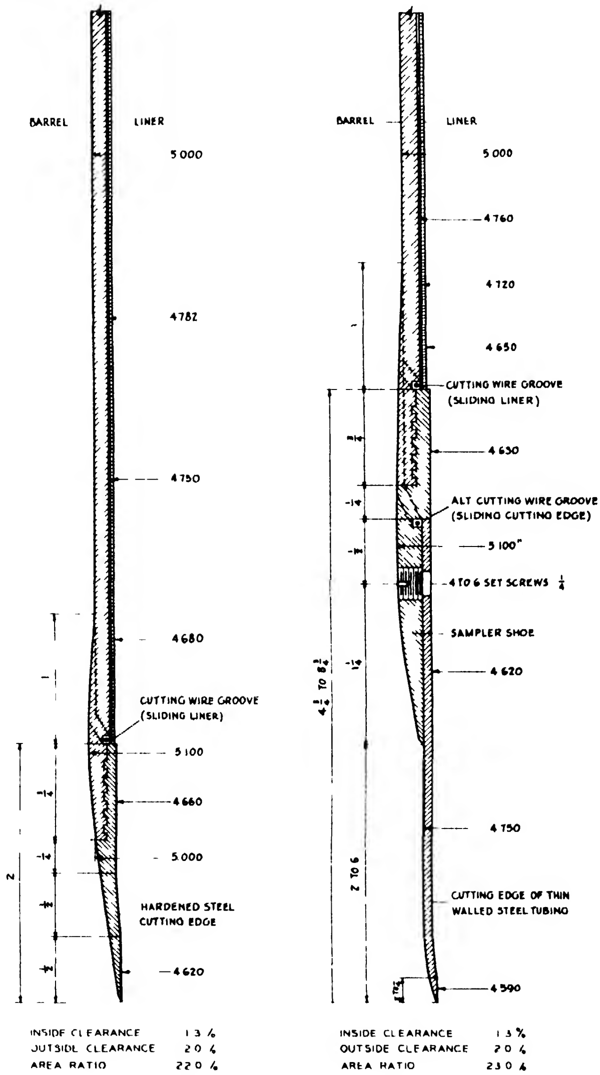
PROVIDENCE SHOE FOR M I T SAMPLER
FIG 193

A suggested design of a streamlined shoe and cutting edge for a 4-3/4-in sampler with liner is shown in Fig 194A The shoe fits inside the barrel, and the outside clearance is produced by a slight upset of the lower end of the barrel, and this upset also strengthens the connection. The wall thickness of both the barrel and the liner is smaller than for the M.I T. sampler, but it is believed to be sufficient for most purposes. The cutting wire groove is placed above the shoe and concealed behind the liner, which is allowed to move upwards for about 0 1 in during the drive, thereby exposing the groove Another design, suggested by the **Waterways Experiment Station,** is shown in Fig 194B and consists in attaching a short section of thin-wall tubing to the shoe This secondary shoe is cheap and easily replaced when damaged, but it increases the distance from the cutting edge to the liner, and the cutting wire may not be effective when placed too far from the cutting edge

Holland samplers.- Two samplers developed in Holland are shown in Fig. 195 and 196 The principal feature of the former, designed by **Van Bruggen (504)** is a liner of hard glass The advantages are decreased inside friction, no danger of

corrosion, and the sample can be inspected without removing it from the liner. The disadvantage is that such a liner is brittle and requires relatively thick walls. Attempts have later been made in this country to retain the advantages of a glass liner and avoid its disadvantages by replacing it with liners of transparent, plastic materials, but even then and with the currently available materials, the required wall thickness is considerably greater than for a metal liner

The check valve in the sampler developed in the **Delft Soil Mechanics Laboratory,** Fig 196, consists of a rubber stopper, manually operated by means of a threaded valve rod The lower part of the liner projects about one inch below the shoe, thereby forming the cutting edge and preventing waste of any part of the recovered sample, but this projection of the liner may buckle when the sampler is used in stiff or gravelly soils A semicircular bead near the lower edge of the liner fits into the sampler shoe and holds the liner in place. The liner alone may also be used in soft soils as a thin-wall sampler, and it is then inverted so that the bead fits into a groove in the sampler head, Fig. 196B.



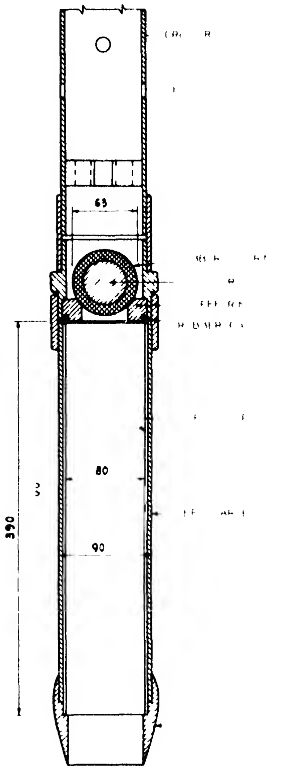
A - 4 3/4' SAMPLER B - VICKSBURG CUTTING EDGE

SHOES AND CUTTING EDGES FOR SAMPLERS WITH LINERS

FIG 194

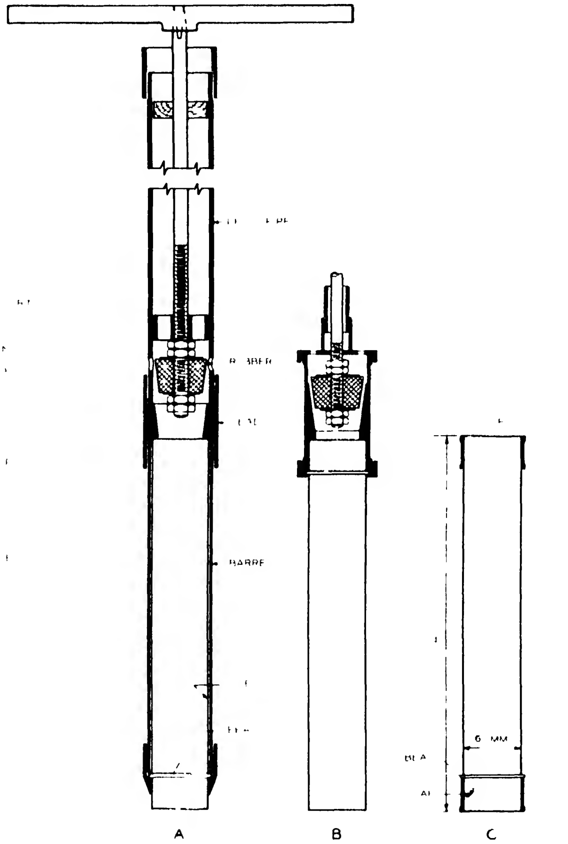
Langer sampler.- The sampler shown in Fig. 197, designed by **Langer (149, 333)**, has been used extensively in France and neighboring countries. In addition to a thin liner, split along a single seam, the sampler has an intermediary barrel which is split into halves in order to facilitate the insertion and removal of the liner, but this intermediary barrel also increases the total wall thickness and the area ratio of the sampler. The sampler has a relatively large check valve and vents, and the intermediary barrel and the liner are removed from the outer barrel by exerting pressure on the check valve housing The sampler is also built in two larger sizes, for samples 4-3/8 in. and 5-1/2 in in diameter.

German and Austrian samplers.- A sampler built by the German Society for Foundation Investigations -- "**Degebo**" -- is shown in Fig. 198. It is the first German soil sampler which is provided with a cutting wire. The catch collar on the sampler head is intended to facilitate the recovery of the sampler in case it should



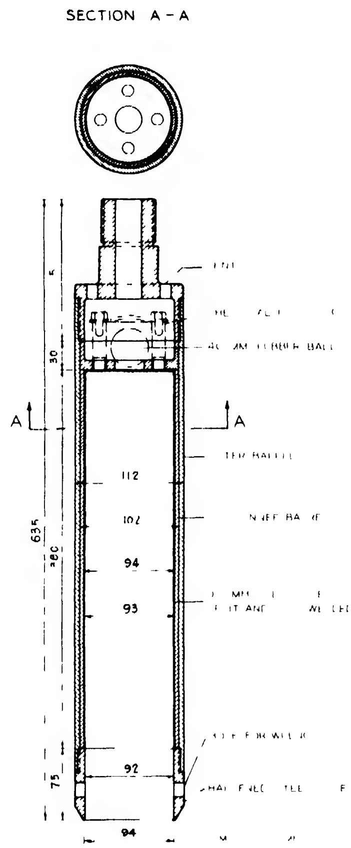
SAMPLER BY J P VAN BRUGGEN

FIG 195



DELFT SOIL SAMPLER

FIG 196



DOUBLE TUBE SAMPLER WITH LINER

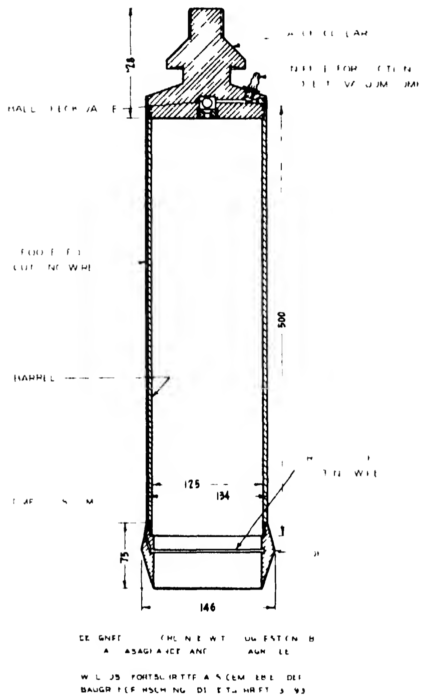
FIG 197

be lost in the bore hole The check valve is supplemented by a nipple for connection to a suction hose and vacuum pump The effective area of the vent and check valve is far too small when the sampler is to be used in a water-filled bore hole and forced rapidly into the soil The outside clearance and area ratio is excessive, but a corresponding sampler with fairly thin walls and integral cutting edge is also used in Germany, **L. Casagrande (106) and W. Loos (229)**, Section 9.3.

A similar sampler was built by the Soil Mechanics Laboratory of the Vienna Institute of Technology, **Terzaghi and Kienzl (969).** At the suggestion of **Fernau (123)**, the check valve was removed and the air hose used first to blow the water and sludge out of the sampler by means of compressed air and later to maintain a partial vacuum over the sample during withdrawal of the sampler, Section 9.4. It

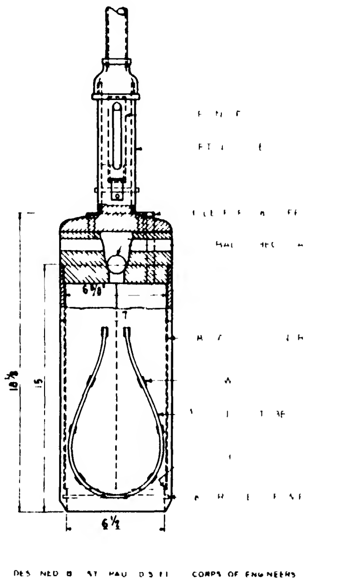
was found that only 30 to 50 blows of the hammer or drilling jars, Fig 32, were required to drive the air-filled sampler into a very stiff clay, whereas 200 to 300 blows were required when the sampler was filled with water, which had to be expelled through the small vent and check valve

St. Paul sampler.- A separate pulling rope for operation of the cutting wire



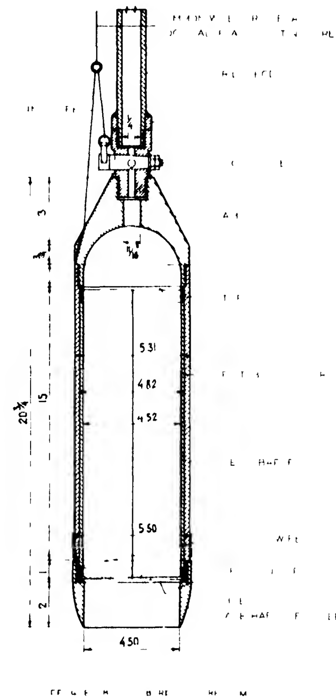
DEGEBO SOIL SAMPLER

FIG 198



6½" SAMPLER WITH AUTOMATICALLY OPERATED CUTTING WIRE

FIG 199



4½ SAMPLER WITH COCK VALVE

FIG 200

is eliminated in the sampler shown in Fig 199 and designed by the **St. Paul District,** Corps of Engineers The cutting wire is attached to and operated by a pin through the lower part of the drill rod, which in turn is attached to the sampler head by means of a sleeve and a bayonet lock A quarter turn of the drill rod permits it to be moved upwards for a distance sufficient to pull the cutting wire through the sample before the withdrawal actually is started Fouling of and sharp bends in the cutting wire are avoided by pushing it through a guide tube which is welded to the surface of the barrel The sampler has a barrel with a relatively thin wall and a liner of thin sheet metal split along a single seam. In experiments at Marshall Creek Dam (112), it was found that this sampler, on account of its relatively small area ratio, caused less distortion of the soil layers than the other samplers used in the experiments However, the short length of the sampler and the absence of a reservoir over the liner increased the danger of overdriving with consequent compression of the sample and formation of a soil cone below the sampler. Planes of failure, forming a cone, were therefore often found in the upper part of the sample when continuous samples were taken; see Fig 74.

Bureau of Reclamation sampler.- A sampler developed by the **U. S. Bureau of Reclamation,** Fig 200, has a split brass liner with the two halves held together by steel rings at the top and bottom However, the principal innovation is that the usual ball check valve is replaced with a cock valve, which is operated by a clamp attached to the pulling rope for the cutting wire

CHAPTER 10
PISTON DRIVE SAMPLERS

10.1 General

Reference is made to Section 4 12 for a discussion of the general principles and the advantages and disadvantages of the various types of piston drive samplers.

Subsurface exploration in general and sampling of soils in particular would be greatly simplified if satisfactory samples always could be obtained by use of a single type of sampler or sampling procedure, but it is improbable that such a sampler ever will be developed on account of the variations in the physical properties of soils Of the various types of samplers developed to date, the drive sampler with a stationary piston has more advantages and comes closer to fulfilling the requirements for an all-purpose sampler than any other type. Nevertheless, it is not always possible to obtain satisfactory samples with this type of sampler, nor is it always superior to other and simpler samplers. Reference is made to Chapter 5 for a discussion of samplers best suited for obtaining samples of the principal types or groups of soils and to Table 8 for a summary of this discussion.

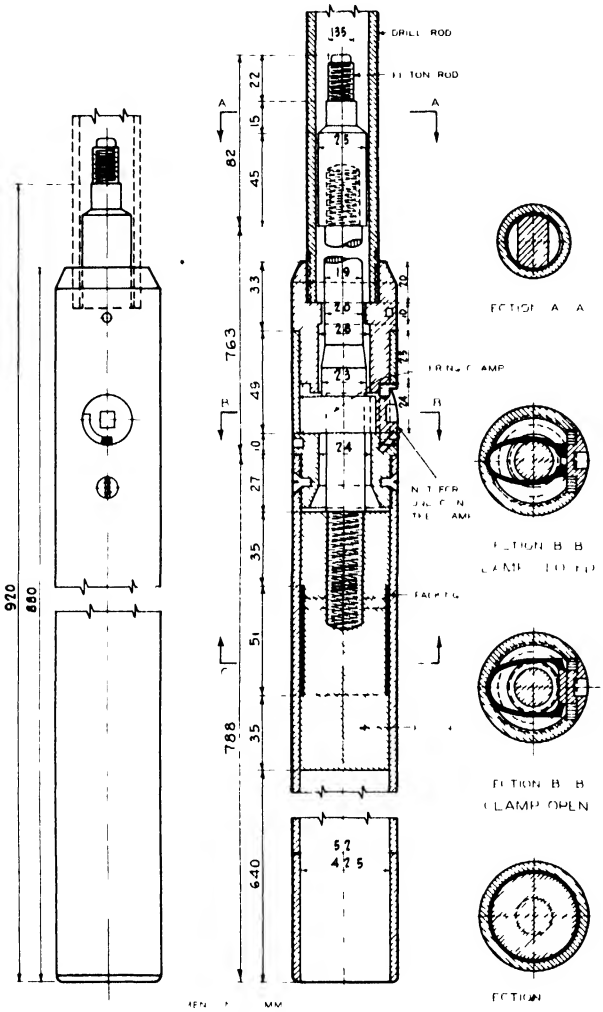
10.2 Scandinavian Drive Samplers with Stationary Piston

Several drive samplers with stationary piston were developed in the Scandinavian countries before this type of sampler was introduced in this country Therefore, the early Scandinavian piston samplers will be described first

Olsson piston sampler.- The first drive sampler with stationary piston was developed in 1923 by the Swedish Engineer-Geologist **John Olsson (539, 540)**, and the latest form of this sampler is shown in Fig 201 The sampler is used for both displacement boring and obtaining representative and fairly undisturbed samples, generally without casing the bore hole.

Before lowering the sampler into the bore hole, the piston rod is pushed down until its lower coupling rests on the sampler head and the piston is flush with the cutting edge. The piston rod is then clamped to the top of the drill rod and the sampler pushed into the soil until the desired sampling depth is reached. The clamp between the piston rod and drill rod is then removed and the piston rod clamped to a yoke with adjustable supports, resting on the ground surface. The piston is thereby held stationary while the sampling tube, by means of the drill rod, is forced past it into the soil until a penetration of 25 in is attained. An elliptical spring clamp then

grips the piston rod under a special collar and prevents a downward movement of the piston during withdrawal This automatic clamp was suggested by the Geotechnical Department of the Norwegian State Railways After withdrawal, a nut at the base of the spring clamp is turned 90 degrees, thereby releasing the clamp, and the piston is pushed down and the sample forced out of the sampling tube. Representative sections of the sample are cut out and preserved in glass jars with a tight fitting top



JOHN OLSSON METHOD OF TAKING EARTH SAMPLE WITH THE MOST UNDISTURBED CONSISTENCY SECOND CONGRESS ON LARGE DAMS WASHINGTON D C - 1936

OLSSON PISTON SAMPLER

FIG 201

The principles of the Olsson piston sampler and the Moran and Proctor sampler, Fig 190, were combined by **Petterson (543)** in a piston sampler with a brass liner in which the entire sample is preserved

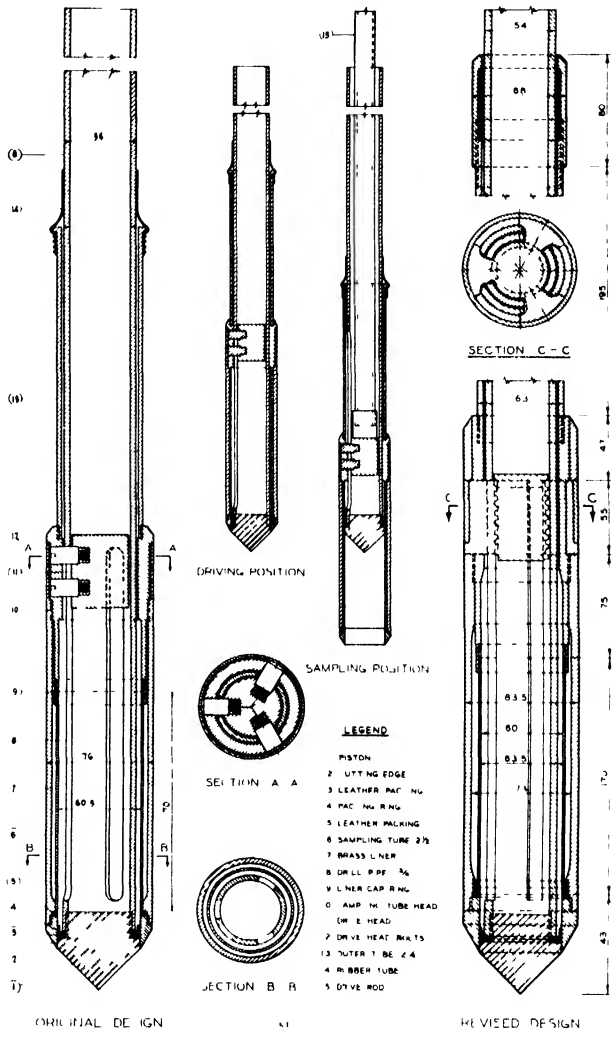
In comparison with the conventional hand-boring methods, used at the time of its development, the Olsson piston sampler not only provided less disturbed samples but also a faster and less costly method of exploring the thick and relatively soft strata of silty and clayey soils which are prevalent in several regions in Sweden

Kjellman piston sampler.- The time required for concurrent coupling and uncoupling of the piston rod and drill rod and the transfer of clamps each time new sections are added constitutes a considerable part of the time required for the entire sampling operation. The concurrent uncoupling of drill rod and piston rod sections during withdrawal is particularly time-consuming since the relative positions of the couplings are changed during the sampling

These disadvantages are partially eliminated in a piston sampler developed by **Kjellman (145, 146, 220)** and shown in Fig 202. The cone-shaped piston is attached directly to the drill rod, whereas the sampling tube by means of six bolts is fastened to a drive head inside the drill rod. Three slots in the lower part of the drill rod permit movement of the bolts, the drive head, and sampling tube. A sleeve attached to the sampler head prevents entrance of soil through the slots in the drill

rod, and a section of rubber tubing at the upper end of the sleeve supplies sufficient friction to hold the sampling tube in its upper position while the sampler is being lowered into the bore hole In a revised design the six bolts are replaced with three segments which are held by flanges in the sampler head and engage threads in a removable drive head, and the rubber tubing on the outer sleeve is replaced with packing and a packing gland

The bolts or segments in the drive head bear against the upper end of the slots in the drill rod during the lowering and preliminary driving of the sampler. The drill rod is in reality acting as a piston rod, and on reaching the desired sampling depth, it is clamped to the ground surface by means of a simple yoke resembling a casing clamp A separate drive rod is then inserted through the drill rod and pressure applied to the drive head, thereby forcing the sampling tube past the piston and into the soil until the piston bears against the drive head and prevents a downward movement of the sampling tube during withdrawal The sample is preserved in the brass liner, which is sealed with caps and rubber bands



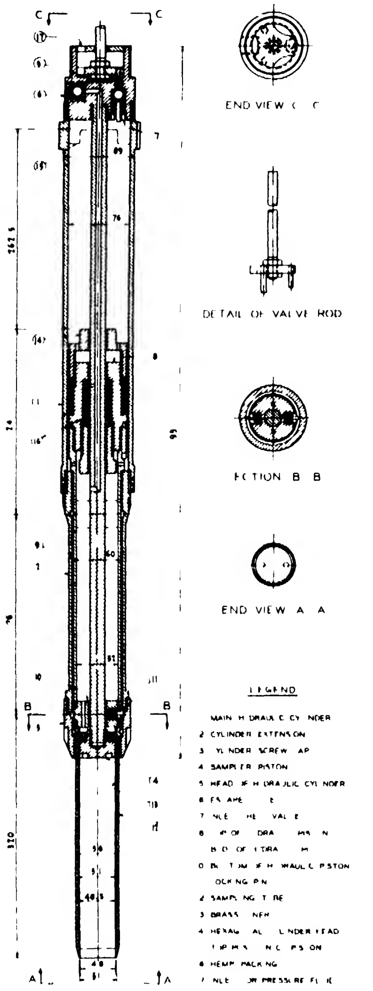
BY WALTER KJELLMAN STATENS GEOTEKNISKA INSTITUT STOCKHOLM SWEDEN

KJELLMAN PISTON SAMPLER

FIG 202

Bretting piston sampler.- Piston rod extensions or auxiliary drive rods are entirely eliminated in a piston sampler with a built-in hydraulic ram, developed by **Bretting (902)** and shown in Fig 203. The head of the hydraulic cylinder is attached to the drill rod, and the hydraulic piston consists of an upper and lower cap with a connecting cylinder The sampling tube with its brass liner is attached to the lower cap, whereas the sampler piston is fastened to a hollow rod which extends through the hydraulic piston assembly to the head of the hydraulic cylinder. The sampler is shown with the hydraulic piston and the sampling tube in their lower position. When the hydraulic piston is in its upper position, the cutting edge of the sampling tube is flush with the sampler

piston and held there by two spring-actuated pins which engage a groove in the upper part of the extension of the main hydraulic cylinder. The lower edge of this groove is rounded so that the locking pins will be pushed in and the sampling tube be free to move downwards when pressure is applied to the hydraulic piston.



A E BRETTING SOIL STUDIES FOR THE STORSTROM BRIDGE DENMARK PROC INT CONF SOIL MECH & FOUNDATION ENG HARVARD 1936 VOL 1

HYDRAULIC PISTON SAMPLER BY BRETTING

FIG 203

The sampler is designed for use in a cased bore hole, and after it is seated on the bottom of the hole, the drill rod is clamped to the casing. When required, additional reaction is obtained by means of a loaded platform or anchorage beams. Water is then pumped through the drill rod into the main hydraulic cylinder and forces the hydraulic piston assembly and the sampling tube down, whereas the sampler piston remains stationary. Air or water over the piston is forced out through several vents, the hollow piston rod, and an escape valve. At the end of the stroke the two locking pins engage a groove between the cylinder extension and its cap After withdrawal the sampling tube is disconnected by unscrewing the cylinder cap, and the brass liner with the sample can then be removed through the top of the sampling tube.

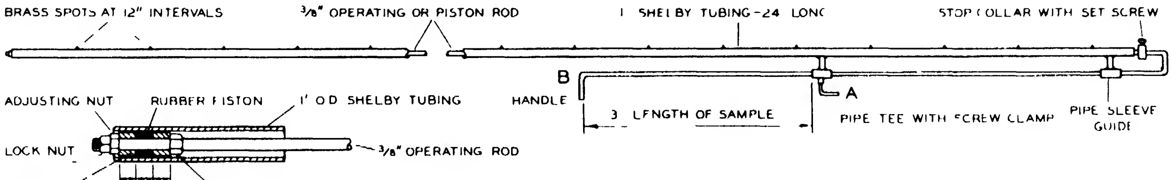
The advantages of elimination of separate piston rods or drive rods, obtained with this ingeniously conceived sampler, are to some extent offset by the relatively small diameter of the sample compared with the diameter of the hydraulic cylinder and the required diameter of the bore hole or casing

10.3 Thin-Wall Samplers with Stationary Piston

As far as is known, the first American sampler with stationary or semi-stationary piston was designed by **Rowe** (622) and used in obtaining samples of the puddle core of El Capitan Dam The sampler consists of a 24-ft long section of 1-in Shelby tubing, Fig. 204, with brass marks at 1-ft intervals for depth determination The upper part of the part of the piston rod is bent into U-shape and passes through two guide tubes, welded to the sampling tube With the piston in its lower position, the clamp A is tightened and the sampler pushed down to the desired sampling depth. The clamp is then released, and the piston rod and piston are held approximately stationary by means of the handle B while the sampler is forced 3 ft into the soil. The piston rod is again clamped to the sampling tube, the sampler withdrawn, and the sample

pushed out of the tube by means of the piston.

Because of the decided advantages of samples with stationary piston, this type was given preference in many of the practical experiments by the Committee on Sampling and Testing and was combined with the thin-wall samplers described in Section 9.3 Further preference was given to the Olsson type sampler with piston



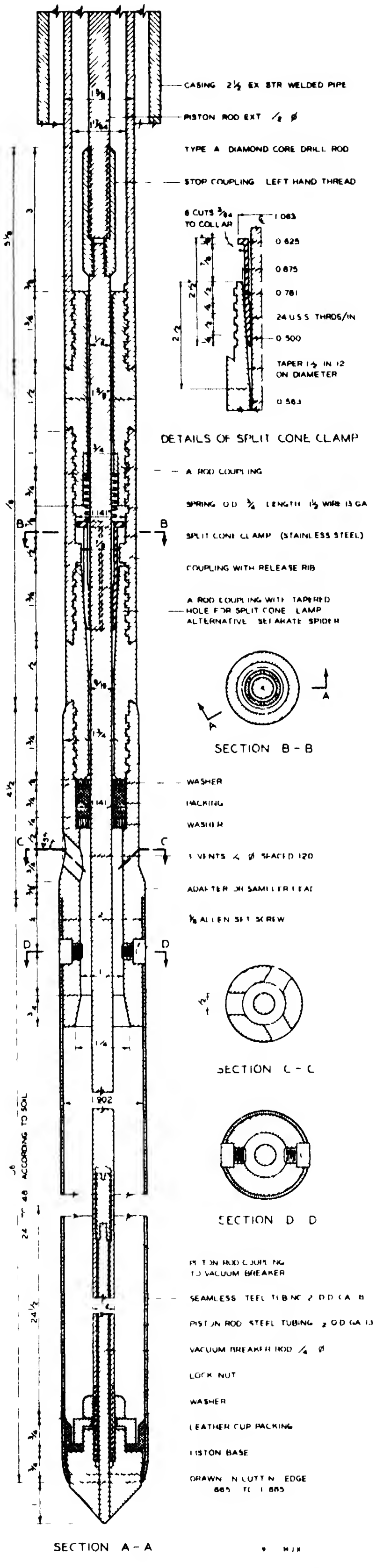
E A ROWE FIELD TESTING DEVICES FOR HYDRAULIC FILLS ENGINEERING NEWS RECORD 1935 VOL 114 P 150

FIG 204 - ROWE PISTON SAMPLER

rod extensions to the ground surface because (1) an open drive sampler can easily be converted into a piston sampler of this type and vice versa, (2) special clamps and connections were developed whereby the clamping operations are simplified and the piston rod extensions can be disconnected before withdrawal of the sampler, (3) the inside diameter of standard diamond core drill rod couplings is too small to permit insertion of a strong auxiliary drive rod as required by the Kjellman sampler, (4) the Kjellman and Bretting type samplers require a standard penetration, but it is desirable to vary the penetration and sample length in accordance with the soil conditions, and (5) a built-in hydraulic drive is unnecessary when the pull-down arrangement, Fig 104, or modern drilling machines with a powerful and long-stroke feed mechanism are used

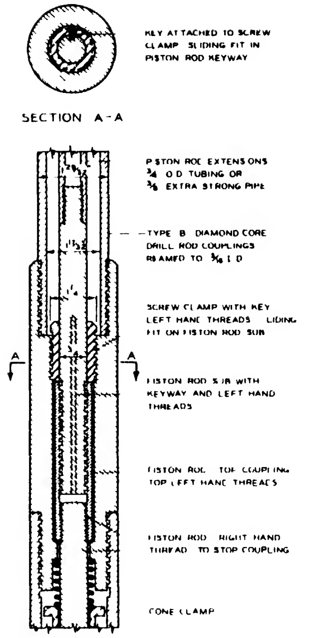
Two-inch sampler.- The sampler shown in Fig 205 is intended for use in a bore hole cased with 2-1/2-in pipe, and it is simply the 2-in thin-wall sampler, Fig. 181, with addition of a piston and an automatic clamping unit above the adapter The tubing is prepared and used in the same manner as for an open drive sampler, but tubing from 6 to 12 in longer than suggested in Section 9.5 can generally be used to advantage. The lower part of the piston is cone-shaped to facilitate pushing aside stones at the bottom of the bore hole. A flat piston requires less space and facilitates determination of the gross and net lengths of the sample, but it was found that there is greater danger that stones may remain under a flat piston, ride the cutting edge during the actual sampling, and thereby disturb the sample, Fig 78

The clamping unit consists of a hollow cone, split into six parts except at the collar. A tapered hole in the lower coupling serves as a spider for the split cone In the position shown in Fig 205 the clamp will permit upward but prevent downward movement of the piston rod irrespective of the position of the piston and length of sample The grip of the clamp can be released by left-hand rotation of the box coupling until the inside rib bears against the collar of the cone clamp and moves it slightly upward, Fig 208A. The packing in the sampler head prevents dirt from



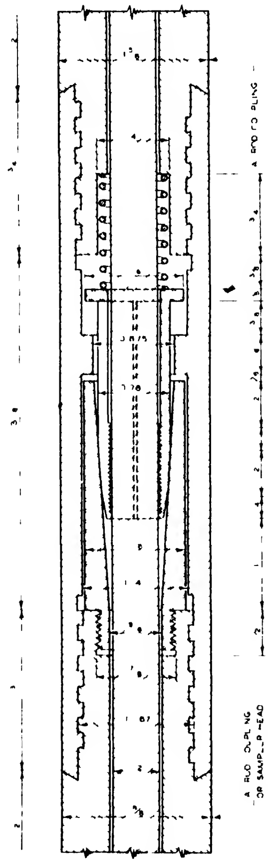
2″ THIN-WALL PISTON SAMPLER

FIG 205



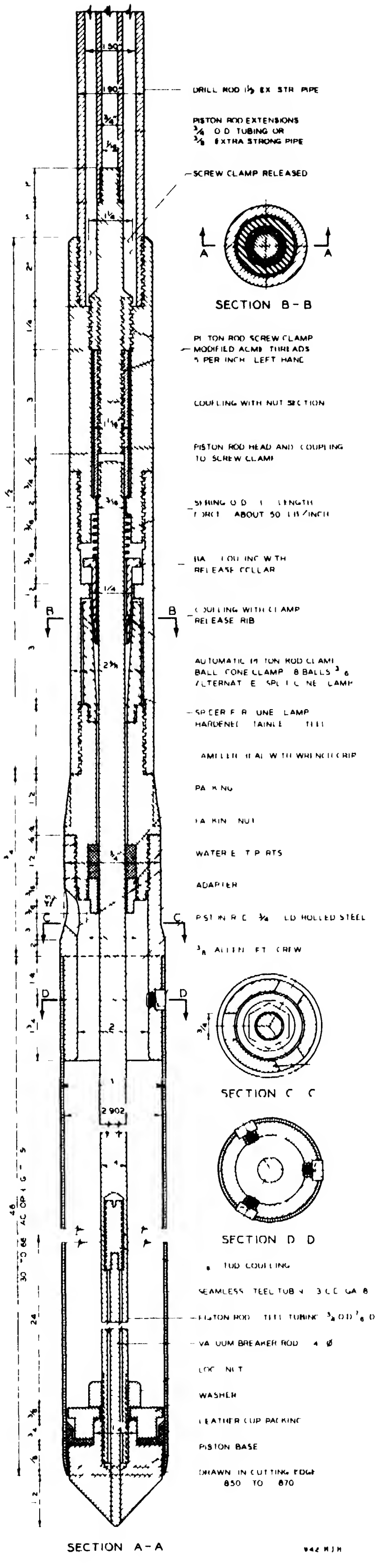
ALTERNATIVE SCREW CLAMP

FIG 207-B



SPLIT CONE CLAMP WITH SEPARATE SPIDER

FIG 206



3″ THIN-WALL PISTON SAMPLER

FIG 207-A

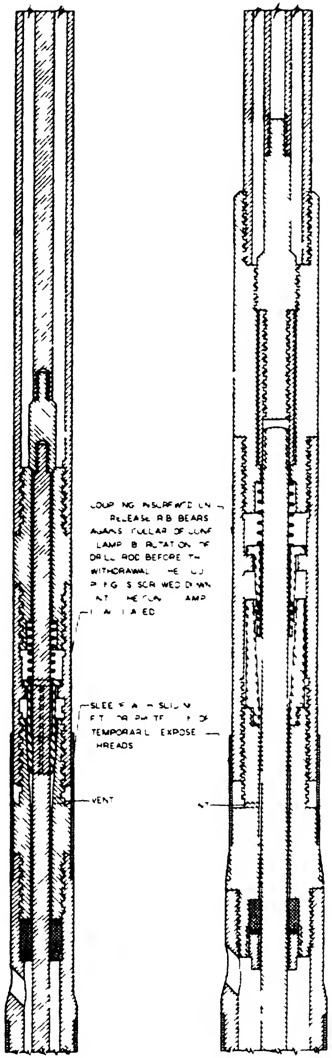
entering the clamping unit. In case the clamp should fail to act on account of rust or wear, the stop coupling between the piston rod proper and its extensions will prevent loss of the rod and piston The upper end of this coupling has left-hand threads, so that the piston rod extensions can be disconnected by right-hand rotation and withdrawn separately

During the practical use of samplers of the above mentioned type, the clamping unit failed to act in a few instances, primarily on account of not being kept clean and free of rust A clamping unit with a separate spider of hardened, stainless steel is more reliable and can easily be exchanged when damaged or worn, Fig 206

In assembling the sampler, the split cone clamp is temporarily released and the piston rod pushed down until the base of the cone point on the piston is flush with the cutting edge The cone clamp is then activated by screwing the box coupling down, and the piston rod is given a couple of light blows to produce a firm grip or a light jamming of the cone clamp This light jamming helps to prevent an upward movement of the piston while the sampler is being lowered into a water-filled bore hole and pushed through soft, disturbed soil at the bottom of the hole, but it is not sufficient to prevent an upward movement of the piston when the sampler is forced into firm soil before starting the actual sampling The piston rod extension must then be clamped to the upper end of the drill rod This may be accomplished by means of a screw-actuated jaw in the drive head for the drill rod or simply by gripping the extending part of the piston rod by pipe wrenches resting on the upper end of the drill rod or drive head

Three-inch sampler.- A 3-in sampler of slightly different design is shown in Fig 207A The split cone clamp is here replaced with a ball cone clamp, which is a combination of the Providence clamp, Fig 212, and the release arrangement shown in Fig 205 The ball cone clamp is less susceptible to fouling by dirt and rust than the split cone clamp, but it tends to score the piston rod and the spider The upper part of the clamping unit contains a screw clamp which holds the piston in its lower position while the sampler is being forced into the soil below the bottom of the bore hole. On reaching the desired sampling depth, the screw clamp is released by a few right-hand turns of the piston rod Further rotation, after completion of the drive, disconnects the screw clamp from the stop coupling, and the piston rod extensions can then be withdrawn provided the drill rod has internal flush couplings When the bore of the couplings is too small to permit passage of the screw clamp, the alternative design shown in Fig 207B may be used The screw clamp proper consists here of a threaded collar with a key, and the clamp is left in the drill rod when the piston rod extensions are withdrawn.

De-activated cone clamp.- In some sampling operations it is desirable to determine the length of the sample before withdrawing the sampler This length can be determined when the actual sampling is carried out with released cone clamp, Fig 208 The clamp between the piston rod extension and the casing or mast, Fig 209 and 210, is released immediately after completion of the drive, and the movement

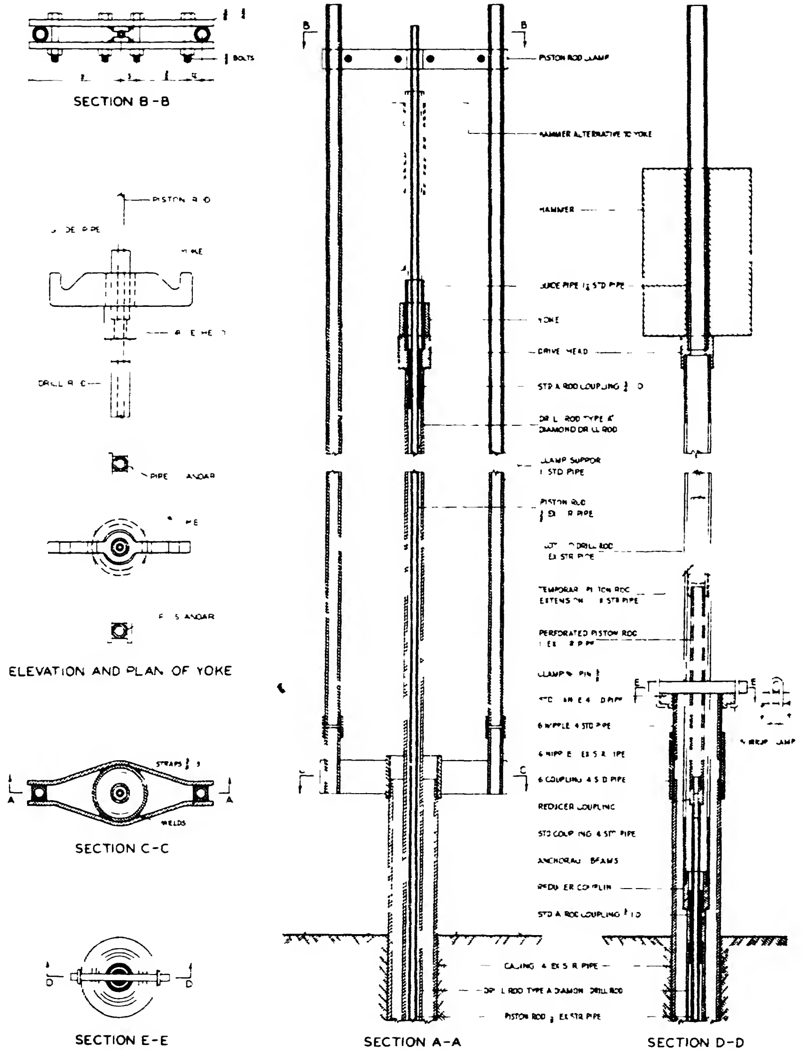


A - REFER FIG 204

B - REFER FIG 206

SAMPLING WITH RELEASED CONE CLAMP

FIG 208



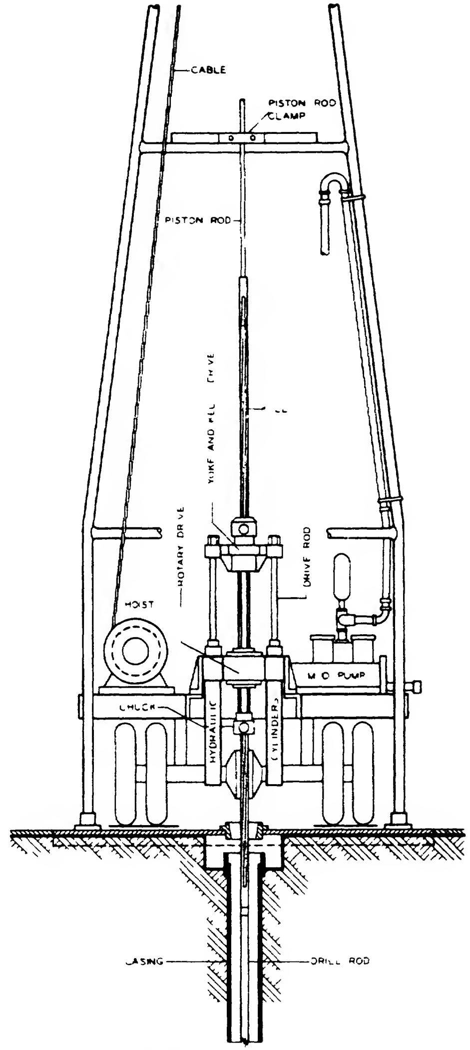
DETAILS

A - CLAMP TO PIPE STANDARDS

B - PIN AND SLOTTED DRILL ROD

METHODS OF CLAMPING PISTON ROD TO CASING

FIG 209



CLAMPING OF PISTON ROD

THROUGH KELLY TO CROSS BAR

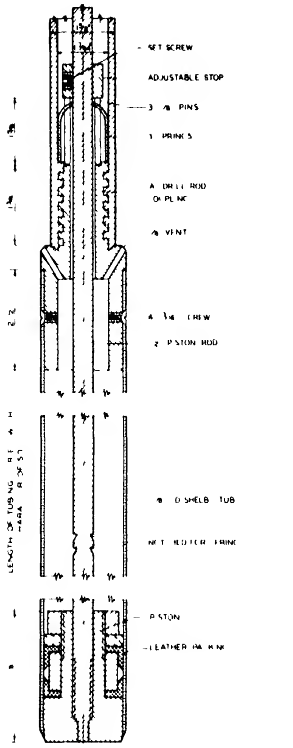
FIG 210

of the piston rod, if any, is then observed The drill rod is thereafter given a few right-hand turns, whereby the box coupling with the released rib is screwed down and the cone clamp is activated

Surface clamping of piston rod.- To hold the piston stationary during actual sampling, the piston rod may be clamped to the casing by either of the arrangements shown in Fig 209 The method shown in Fig 209A is the simplest and most convenient when the driving force is applied by means of a yoke or wrenches, Fig 104. The clamping arrangement shown in Fig 209B requires a slotted section of drill rod, a perforated section of piston rod, and fairly close adjustment of these sections However, this clamping arrangement does not restrict the space above the drill rod, and the use of static weights, standard jacks, or a drop hammer in forcing the sampler into the soil is easier than with the arrangement shown in Fig 209A When a drilling machine of the type shown in Fig 37 and 38 is used, the piston rod extension may be carried up through the hollow drive rod or kelly and clamped to a crossbar in the mast, Fig 210 This simple method was suggested by **T. B. Goode** of the Waterways Experiment Station, Corps of Engineers When the casing is not firmly embedded in the soil and is used to furnish reaction for a hydraulic ram or a pull-down arrangement, Fig 104, it may rise slightly when the sampler is forced into the soil and will thereby cause the piston rod to move upwards and excess soil to enter the sampler Likewise, when great force is applied to the drill rod by means of the feed mechanism of a drilling machine, the machine and the mast may be lifted and a piston rod, clamped to the mast, moved upward In such cases additional reaction must be provided by means of earth anchors, "deadmen", or a loaded platform

Withdrawal of piston rod.- With the piston in its lower position, the couplings of the piston rod are a little above those of the drill rod, and the assembling of the two rods during lowering of the sampler is easily accomplished However, the relative positions of the couplings are changed during the drive, and concurrent withdrawal of the two rods is then inconvenient and time-consuming Therefore, after completion of the drive, the piston rod extensions are rotated until the previously described coupling with left-hand threads is disconnected, whereupon they are withdrawn The drill rod and sampler are now given a couple of right-hand turns to separate the sample from the soil in situ and are then withdrawn

Providence samplers.- A 2-in thin-wall piston sampler, designed by the **Providence District,** Corps of Engineers, **Fahlquist (120),** is shown in Fig 211 The original piston rod clamp consisted of an adjustable stop coupling and springs engaging notches in the piston rod This clamp was later replaced with the ball cone clamp shown in Fig 212 To release this clamp after withdrawal of the sampler, the drill rods and piston rod extensions above the clamp are disconnected and the housing with the steel balls is removed from the tapered sleeve or spider. The clamp is re-inserted after a new tube has been fastened to the adapter and the piston pushed down to the cutting edge A similar and very simple sampler with an



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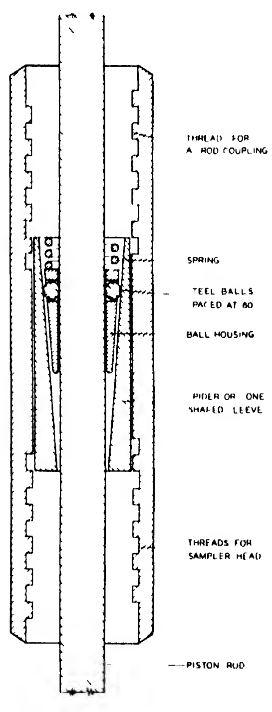
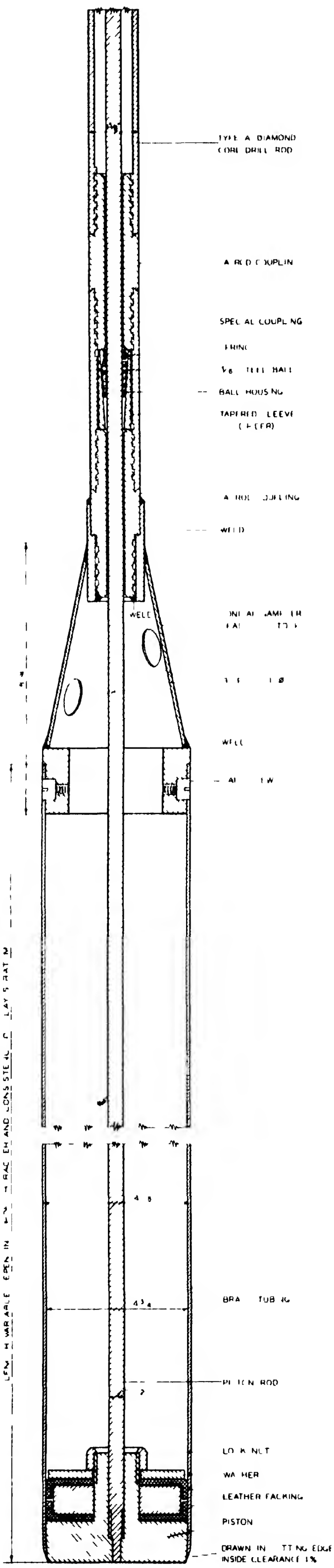
PROVIDENCE 2" THIN-WALL
PISTON SAMPLER
FIG 211



DESIGNED BY PROVIDENCE DISTR T CORPS OF ENGINEERS

PISTON ROD BALL-CONE CLAMP
FIG 212



UNDISTURBED SAMPL NG OF SED MENT EQ PMENT AND PR CEDURE
REPORT BY PROVIDENCE DISTRICT CORPS OF ENGINEERS 194

PROVIDENCE 4¾' THIN-WALL
PISTON SAMPLER
FIG. 213

internal diameter of 4-3/4 in is shown in Fig. 213

Semi-stationary piston.- The piston rod extensions may be eliminated by providing the piston or piston rod proper with a clamping arrangement which holds the piston in its lower position and which, upon reaching sampling depth, can be released by means of a weight fastened to a wire rope or light chain and lowered through the drill rod The weight or overshot attaches itself to the piston, and the rope or chain is fastened to the boring mast or tripod A downward movement of the sampler and corresponding pull on the rope releases the clamp, and a downward movement of the piston during the actual sampling is prevented The first sampler of this type was designed by **Kjellman (331)**, and a similar sampler, but with a wire rope permanently attached to the piston and passing out through an opening in the sampler head or lower part of the drill rod, has been developed and used to a considerable extent by the **New Orleans District**, Corps of Engineers Elimination of the piston rod or its extensions by such arrangements reduces the time required for a sampling operation, but a rope or chain cannot prevent an upward movement of the piston and entrance of excess soil into the sampler

10.4 Composite Samplers with Stationary Piston

Although a thin-wall sampler usually will cause less disturbance of the soil than a composite sampler with liner and consequent larger area ratio, the latter type has definite practical advantages which may make it preferable in some cases, especially when the diameter is large and/or when the sampler is used both for displacement boring and sampling.

Large-diameter sampler with liner.- A design of a 4-3/4-in sampler with liners and provision for use of a cutting wire is shown in Fig 214A The sampler is intended for use within a 6-in casing or in an uncased bore hole stabilized with water or drilling fluid, but it is not strong enough for use in displacement boring except in very soft soils Such a sampler but with slightly different dimensions and details has been built by the **Waterways Experiment Station**, Corps of Engineers, and field trials are currently in progress

The piston rod clamping unit consists of a split cone clamp, Fig 214B, and a screw clamp similar to the one previously described and shown in Fig 207B The cutting wire groove is made in the main barrel directly above the shoe and is concealed behind the liner during lowering of the sampler A small clearance is provided between the top of the liner and the sampler head, and the friction between the liner and the piston and sample will cause this clearance to be closed during the actual sampling, thereby exposing the cutting wire groove Samples of many types of soil can be retained without use of a cutting wire, but even then cutting the sample free by means of a wire has the advantage that it causes less disturbance of the lower part of the sample than separating the sample from the soil in situ by rotation and/or a direct pull

A continuous liner from shoe to sampler head is preferable from the standpoint of reducing disturbance of the soil and avoiding loss of the sample, but the upper part of such a liner constitutes wasted material because of the space occupied by the piston Therefore, the liner is tentatively divided into two sections, of which the upper section or dummy liner receives the piston and partially disturbed soil immediately below the piston After withdrawal, this soil is pushed out of the dummy liner and preserved in a separate container or encased in paraffin. By having on hand dummy liners of various lengths, and corresponding lengths of the main liner, waste of liner material can be avoided when it is necessary to change the depth of penetration and length of sample on account of a change in soil conditions Furthermore, it is not necessary to remove the vacuum breaker rod when the sample is cut below the dummy liner

The main liner may also be divided into sections, 12 to 24 in long Shipment, storage, and handling of the sample in the laboratory is thereby facilitated, and the liner sections can be used again after removal of the sample. However, in case of imperfect alignment, the joints between liner sections may cause disturbance of the surface of the sample, and leakage through these joints may cause loss of the sample or part of the sample A satisfactory method for aligning and sealing the joints

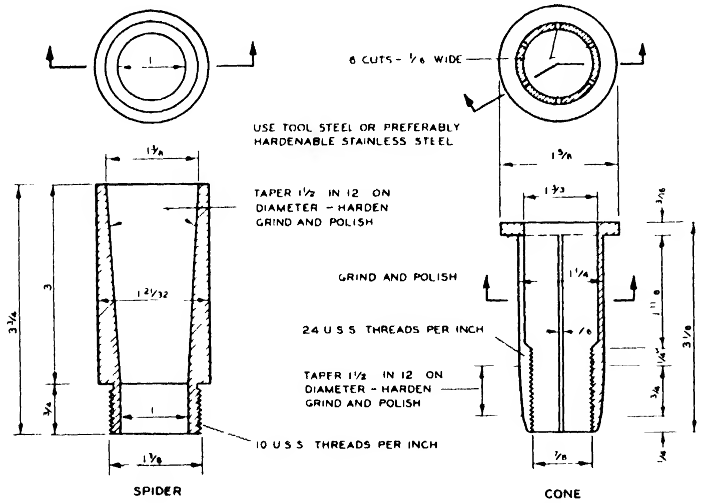
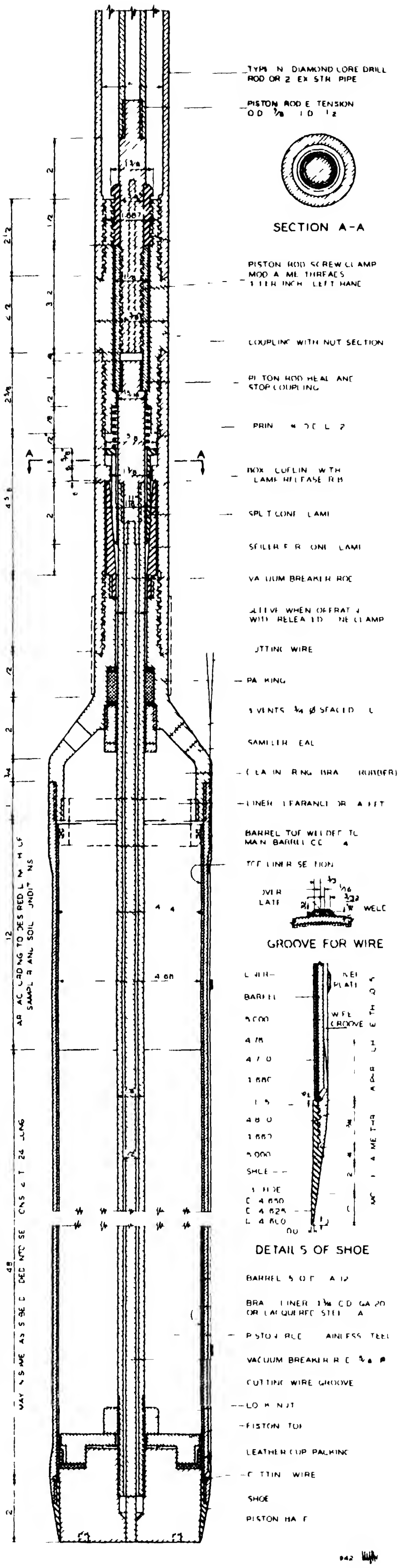


FIG 214-B- DETAILS OF SPLIT CONE CLAMP FOR "N" ROD



4¾ PISTON SAMPLER WITH LINER

FIG 214-A

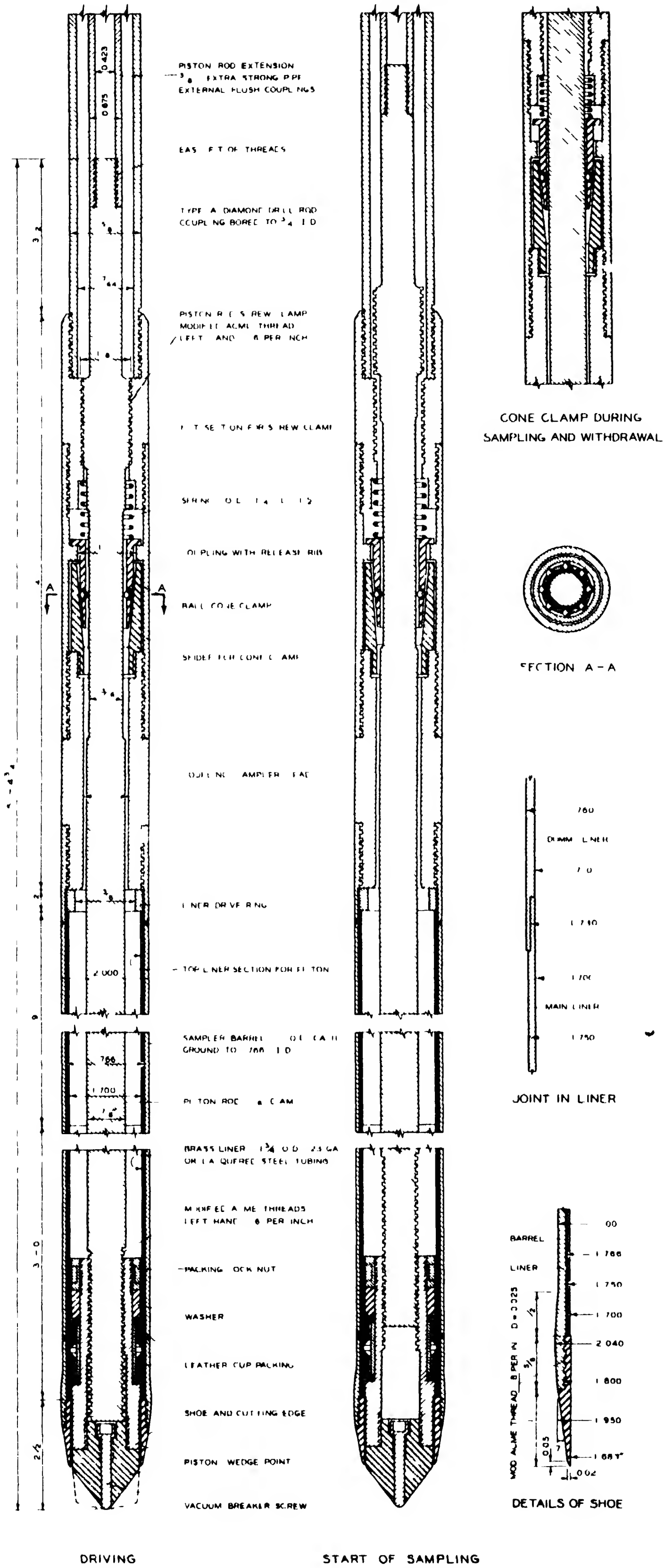
between thin-wall liner sections has not yet been developed Thin outside slip rings or couplings have been used, but it is difficult to obtain the required close fit on account of the tolerance on the outside diameter of commercially available tubing, and the slip rings also cause a slight increase in the over-all wall thickness and the area ratio Fairly satisfactory alignment of the liner sections can generally be obtained by moving the piston through the sampler after the liners have been inserted

Until the sampler is out of the soil, leakage through the joints between liner sections has its primary source in flow between the top of the liners and the sampler head Sealing of this joint will decrease the danger of leakage through the lower joints When the cutting wire is not to be used, the upper joint may be sealed with a gasket between the liner and the sampler head When the cutting wire is to be used and the liners must move upward to expose the groove for the wire, the upper joint may be sealed with an auxiliary sealing ring, shown dotted in Fig 214A Even when the upper joint is sealed, leakage may occur through the lower joints after the sampler is out of the soil and water or air can enter through the shoe and cutting wire groove Such leakage may cause loss of samples containing strata or seams of pervious soil

Samplers used for displacement boring.- The Olsson and Kjellman samplers, Fig 201 and 202, and most of the piston samplers described in the following sections are generally used in uncased as well as cased bore holes and for both displacement boring and sampling Reference is made to Section 2 12 for a discussion of the advantages and limitations of displacement boring without casing The diameter of samplers used for this purpose is generally limited to 2 to 3 in on account of the resistance to penetration of the closed sampler and the consequent requirement of increased strength of the sampler and drill rods

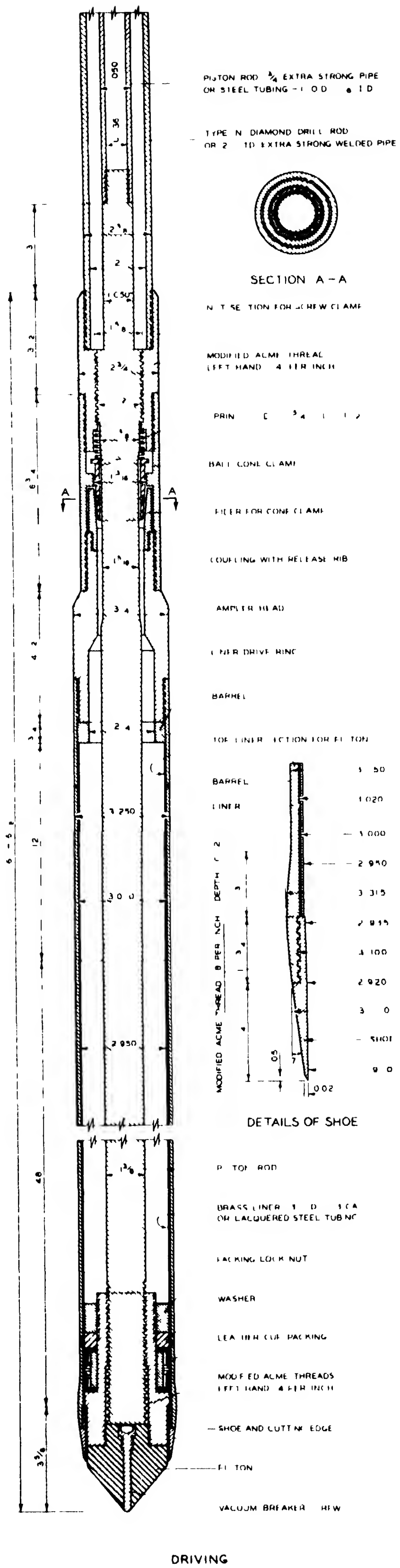
The thin-wall samplers shown in Fig 205 and 207 can be used for displacement boring in soft soils, but greater wall thickness of the tubing and stronger clamps and piston rods are required for displacement boring in firm soils and it is more economical to use a sampler with a strong working barrel and thin-wall liners Liners in samplers of small diameter cause a very material increase in the area ratio and thereby also in the tendency to disturb the soil in the sample, such samplers may, nevertheless, be used to advantage in reconnaissance and some detailed explorations

The samplers shown in Fig 215A and B are intended for displacement boring and sampling through uncased bore holes or 2-1/2-in and 4-in casing The upper part of the barrel has an internal upset to provide sufficient thickness for the threads and to preserve the smooth exterior of the sampler and thereby decrease the penetration resistance Because of the internal upset, the liner must be inserted and removed through the bottom of the barrel It will generally be possible to push the liner and sample out by means of the piston, but direct pressure can be applied to the liner through the drive ring when the barrel has been disconnected from the sampler head Since the top liner section or dummy liner is used repeatedly, it is



1 3/4" PISTON DRIVE SAMPLER

FIG 215-A



3" PISTON DRIVE SAMPLER

FIG 215-B

machined to close tolerances and has a slightly greater outside diameter than that of the main liner, consisting of standard, seamless brass tubing To prevent leakage and loss of the sample, a shallow shoulder or slip joint is provided between the dummy liner and the main liner If the main liner is divided into sections, the joint between the dummy liner and the sampler head should be sealed, as in the sampler shown in Fig 214A After withdrawal and pushing the sample and liner out of the barrel, the dummy liner is moved slightly upward until the slip joint is open and the sample can be cut flush with the top of the main liner

The piston is held in its lower position by a threaded section of the piston rod and a nut section in the sampler head A few right-hand turns of the piston rod extensions, upon reaching sampling depth, will disengage the piston rod from the nut section The lower end of the piston rod is connected to the piston through easy fitting threads of the same pitch as those in the nut section, so that the piston will not be retracted when the piston rod is rotated to release the screw clamp A downward movement of the piston during withdrawal is prevented by a ball cone clamp A split cone clamp could also be used, but the ball cone clamp is preferable in this case because it provides greater vent area The sampler has inside venting, since outside vents may become clogged with soil when the sampler is used in uncased holes The effective vent area is small, and water should, insofar as possible, be prevented from entering the space over the piston, which therefore is provided with double leather packing The piston has a vacuum breaker screw, but it needs not be removed when the sample is cut below the dummy liner A sampler of the design shown in Fig 215A has been built by the Raymond Concrete Pile Co , but adequate field trials have not yet been made

10.5 Sampler with Stationary Piston and Steel Foils

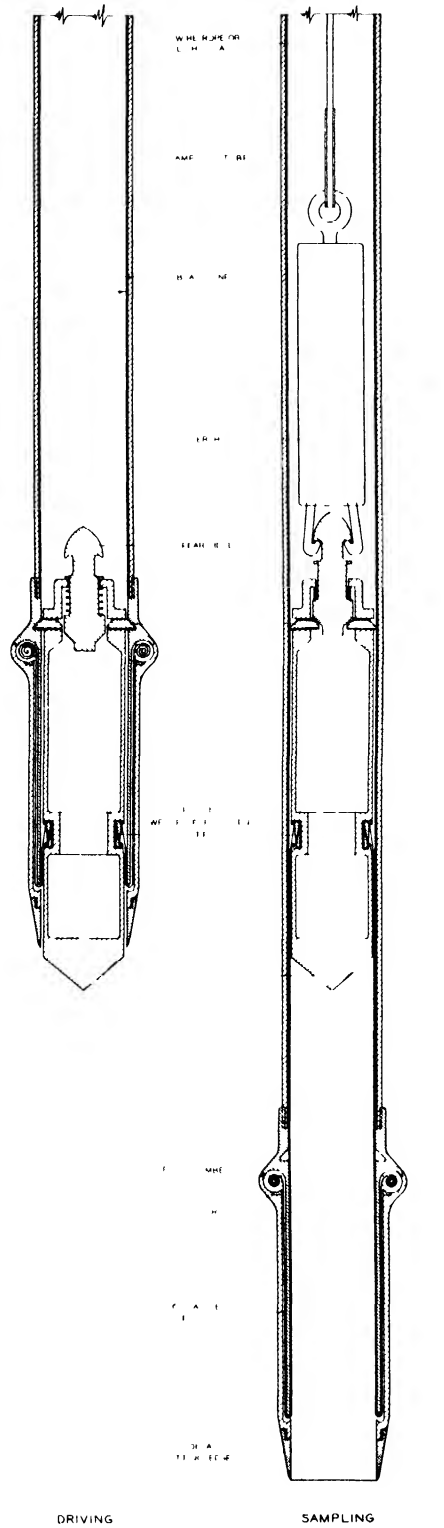
The principal causes of disturbance of samples during drive sampling are (1) displacement of soil by the sampler walls, (2) inside friction or friction between the sample and the sampler or its liner, and (3) pressure on top of the sample The disturbance caused by soil displacement can be reduced to a very small amount by use of thin-wall samplers, and the pressure on top of the sample can be regulated and its harmful influence eliminated by use of a sampler with stationary piston By providing inside clearance at the cutting edge, the inside friction can be decreased, but it cannot and should not be entirely eliminated in this manner In the drive samplers so far described the inside friction may cause some disturbance close to the surface of the sample, and it imposes a definite limit on the length of undisturbed sample which can be obtained in a single operation

A new method of eliminating detrimental effects of the inside friction has recently been developed by **W. Kjellman and T. Kallstenius** of the Swedish Geotechnical Institute. The method consists in surrounding the sample with a number of very thin steel strips or foils, which are attached to a stationary piston By means of an ingenious arrangement, these foils move into and upward in the sampler in such a

manner that there is no movement between the sample and the foils A sampler designed according to this principle is shown diagrammatically in Fig 216 This figure and the following general discussion is based on personal communications, **Kjellman (147)**, and the state of development of the sampler in March 1947 Experiments with and further development of the sampler were in progress at that time, and various changes and improvements have been made in the intervening period

The sampling tube proper consists of a steel tube and thin-wall liner with an internal diameter of 2 67 in and divided into 8-ft long sections To this tube is attached a double-walled section which contains magazines and channels for the steel foils and is terminated with a shoe and sharp cutting edge The magazines or foil chambers contain 16 spools for the foils, each of the latter being 1/2 in wide and 0 02 in to 0 04 in thick The foils enter the sampler through slots above the cutting edge and are fastened to the piston by means of wedge-shaped rings The piston is held in its lower position by locking pins engaging a groove above the foil chamber On reaching sampling depth, a weight on a wire rope or light chain is lowered through the drill rod and attaches itself to the spearhead on top of the piston A pull on the chain and spearhead releases the locking pins, and the sampler is forced into the soil while the chain is fastened to a yoke and prevents a downward movement of the piston At completion of the drive the piston is again locked to the sampling tube After withdrawal, the sample can easily be removed from the tubes by pulling on the steel foils, or the latter may be cut and the sample, still surrounded by the foils, shipped to the laboratory in the liner sections

The chain attached to the piston will prevent a downward but not an upward movement of the latter, and it is possible that excess soil may enter the sampler during the first part of the



SWEDISH PISTON SAMPLER WITH STEEL FOILS

FIG 216

drive. However, entrance of excess soil can be prevented by replacing the chain with a piston rod extending to the ground surface

During the sampling, friction between the sampler and the steel foils produces tension in the latter and a downward force on the piston Friction and adhesion between soil and foils will hinder or prevent a downward movement of the sample and cause a part of the weight of the sample to be transferred to the foils, thereby increasing the tension in the foils After the vertical pressure in the lower part of the sample reaches a value sufficient to prevent entrance of excess soil, it is probable that the weight of additional soil entering the sampler will be transferred to the steel foils and that additional penetration will not cause an increase in vertical pressures. Therefore, both vertical and horizontal stresses, the tendency of the sample to deform laterally, and the required inside clearance at the cutting edge will be smaller than for a sampler without steel foils When the vertical pressure in the sample and on the soil below the sampler does not increase beyond a value less than that causing disturbance and plastic downward deflection of the soil layers, the safe depth of penetration is extremely large and theoretically infinite, in which case the length of sample which can be taken in a single operation depends only on the strength of the sampling tube and the steel foils

The bulge formed by the foil chamber will cause a large increase in penetration resistance, but its influence on entrance of excess soil and disturbance of soil below the sampler can be reduced to a very small amount by providing adequate distance from the cutting edge to the foil chamber However, the double-walled tubing below the foil chamber has of necessity a relatively large area ratio, about 30 percent for the sampler shown, and there is a possibility that it may cause entrance of excess soil and/or partial disturbance of the soil before it enters the sampler In general, this possibility exists when samplers with double walls or liners, Fig 214 and 215, are used in soft soils

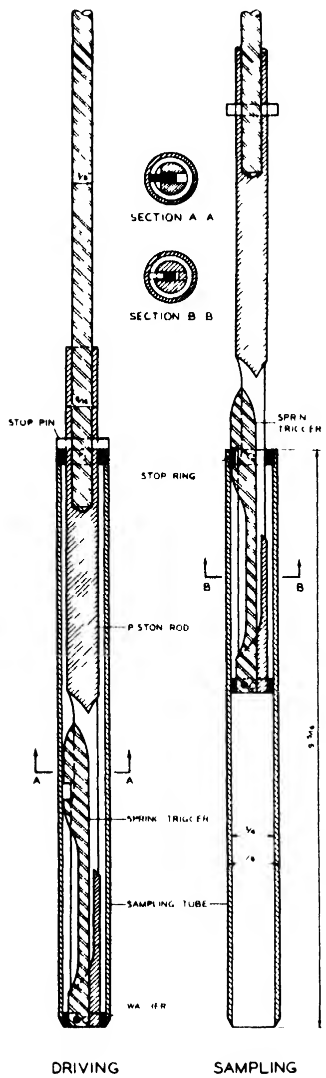
As mentioned in Section 4 12, displacement of a large amount of soil may cause disturbance below the sampler even though entrance of excess soil is prevented by means of a stationary piston, and such a disturbance does not necessarily appear as visible distortions or planes of failure in the sample The disturbance caused by a large area ratio can be decreased and even eliminated by use of a shoe with a small angle of taper, Section 4 11, but the allowable maximum value of the taper for a given area ratio has not yet been determined definitely

Several changes and improvements in the design of the sampler have been made during the last year. The chain to the piston has been replaced with a piston rod, the liner has been eliminated, the diameter of the foil chamber has been decreased materially by a rearrangement of the foil spools, and in one model the double-walled tubing has been replaced with a section of thin-wall tubing These changes will reduce and may eliminate the above mentioned possible disturbance of the sample by the foil chamber and/or double-walled tubing. Samples of soft soil up to 20 m in length have been obtained in a single operation.

The sampler with stationary piston and steel foils constitutes an important step forward in the development of equipment for obtaining undisturbed soil samples It presents a positive means of eliminating disturbance of the sample by the inside friction, and its general principles deserve most serious consideration

10.6 Drive Samplers with Retracted Piston

Concurrently with the development of samplers with stationary piston in the Scandinavian countries, samplers in which the piston is retracted to the sampler head before the start of the actual sampling were developed in this country and used extensively in practical sampling operations



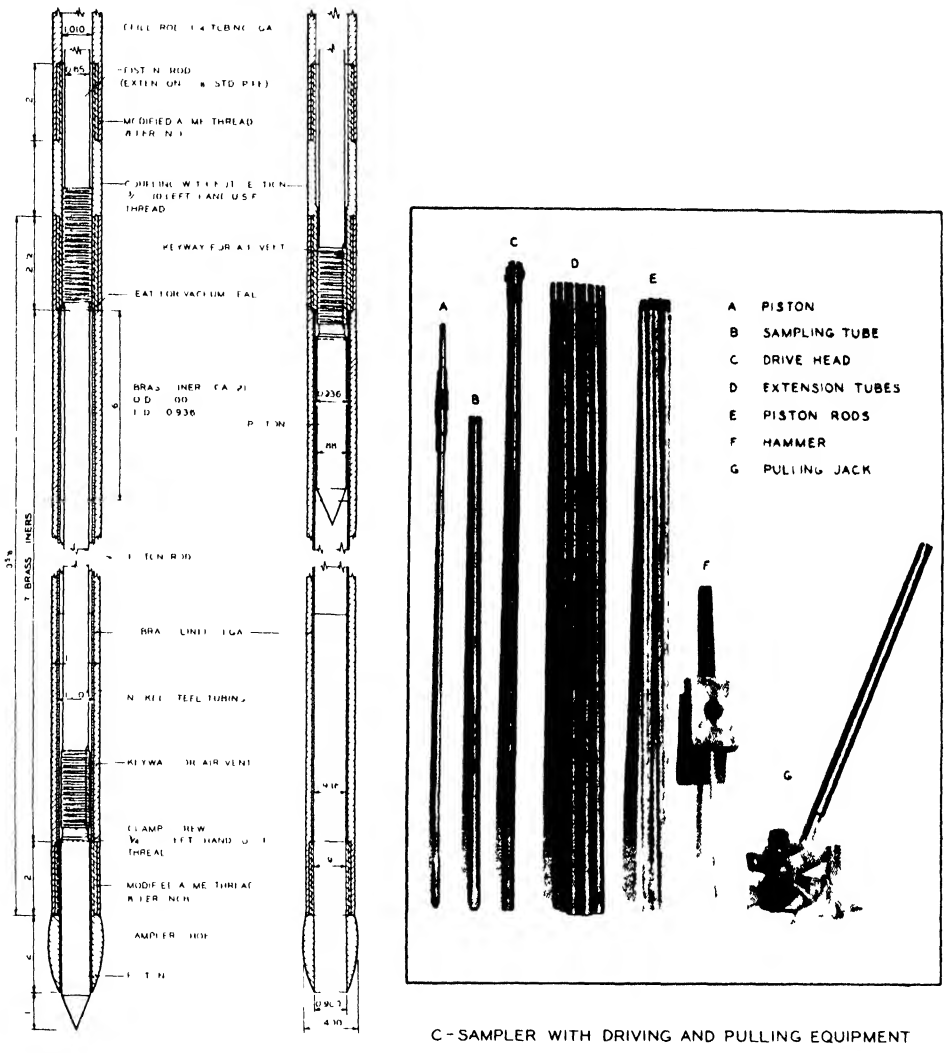
DAVIS PISTON SAMPLER

FIG 217

The first of these samplers was designed by **C. A. Davis (702)** and principally intended for exploration of peat deposits It is therefore known as the Davis Peat Sampler, although it also is used for obtaining samples of other soft or medium soft soils An improved design of this sampler, **Stockstad (178)**, is shown in Fig 217 The sampler is operated by means of a single rod connected to the piston, and the need of a separate piston rod is eliminated by a trigger arrangement in the piston The sampling tube is free to slide over the piston, but its movements are limited by a stop pin at the upper end and a washer at the lower end of the piston The stop pin transfers pressure from the rod to the tube when the closed sampler is pushed into the soil Upon reaching sampling depth, the rod and piston are pulled up for a distance of about 6 in whereas the sampling tube remains stationary In the upper position of the piston, the trigger engages a stop ring on the sampling tube and locks it to the piston The sampler is now ready for the actual sampling, and the rod is again pushed down After withdrawal, the trigger is released and the sample pushed out of the tube by means of the piston This sampler is very simple in both construction and operation, and it has been used to a considerable extent in reconnaissance explorations However, the retraction of the piston creates a partial vacuum in the sampling tube and may thereby cause soft soil to be forced into the tube before the actual sampling The resulting sample is representative of average conditions but seriously disturbed.

The creation of a vacuum in the sampling tube by retraction of the piston is avoided in piston samplers designed by **O. J. Porter (163, 347, 515)** for the Materials

and Research Department, Division of Highways, State of California, **Stanton (176, 177, 550).** These samplers require piston rods extending above the drill rod. The piston in the 1-in sampler, Fig 218, is held in its lower position by a threaded section of the upper part of the drill rod, engaging left-hand threads in the sampler



A-DRIVING

B-SAMPLING

C-SAMPLER WITH DRIVING AND PULLING EQUIPMENT

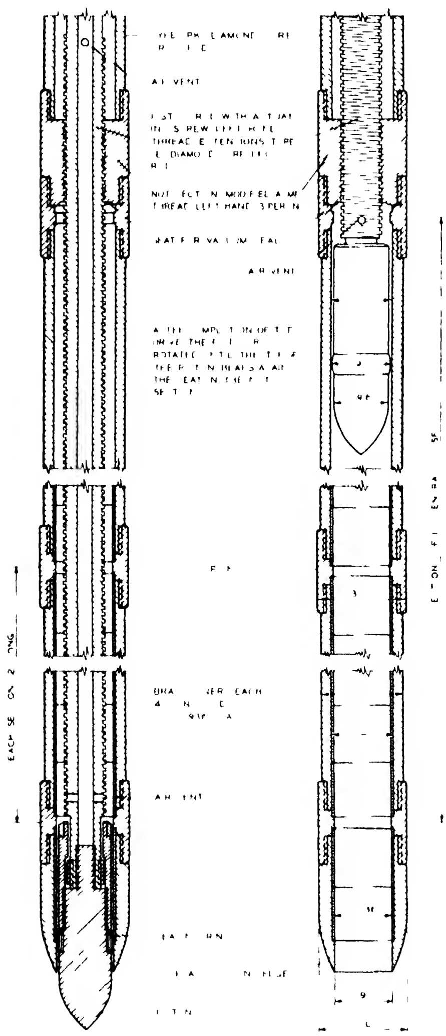
1" PORTER PISTON SAMPLER

FIG 218

head When sampling depth is reached, the piston rod is rotated until the threaded section is disengaged from the sampler head The rod is then retracted and again rotated until the threaded section at its lower end is firmly engaged by the threads in the sampler head During retraction of the piston, air can pass into the sampling tube through the keyway in the threaded section of the rod and through the small clearance between the piston and the liners. A small space is temporarily left between the top of the piston and the sampler head to permit escape of air or water as

the sample enters the tube When the drive is completed, the piston rod is rotated until the top of the piston is in contact with the sampler head and passages to the vent are closed The sampler is then withdrawn, the shoe disconnected, and the liner sections with the sample pushed out Two shoes are provided, one with a diameter of 1 400 in. for use in soft and cohesive soils, and one with a diameter of 1 300 in for use in cohesionless and stiff soils

The sampler is generally used without casing and can be pushed into soft soils by hand or driven by a small hand hammer, Fig 218C A small, portable, gasoline-driven hammer is often used for driving the sampler into stiff and dense soils Lugs on the drive head of the drill rod and slotted hole in the hand hammer make it possible to use the latter for withdrawing the sampler A very effective pulling jack is also available for this purpose The sampler is sturdy and compact, it requires but little auxiliary equipment, is easy to operate, and well suited for reconnaissance explorations



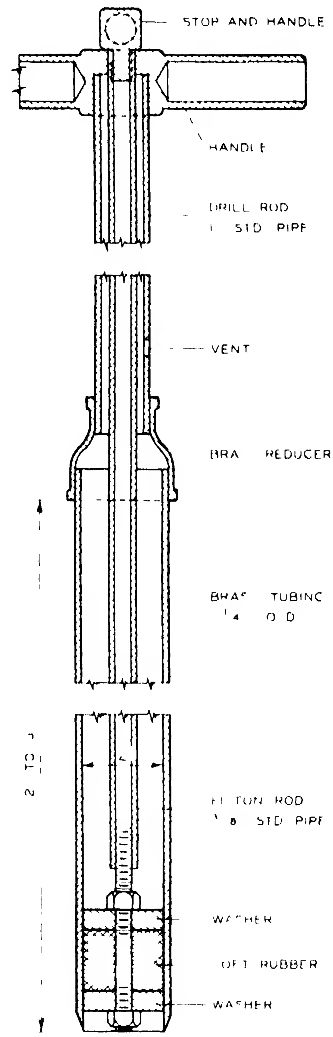
DRIVING SAMPLING

2" PORTER PISTON SAMPLER

FIG 219

The 2-in sampler, Fig 219, is operated as the 1-in sampler, but the sampling tube is divided into 12-in long sections, and the piston rod is threaded from the piston to the first extension rod It thereby becomes possible to vary the length of the sampler and the retraction of the piston in accordance with the soil conditions Three to five sections are generally used Inside venting is provided by the hollow piston rod and small holes near its top and bottom As suggested by **C. M. Sanborn**, the vents may also be placed in the sampler head or nut section, Fig 121, and weakening of the piston rod by holes is thereby avoided The sampler is sturdily built and has a very large area ratio To decrease the consequent danger of disturbance of the soil, additional shoes, longer and with a smaller taper than shown in Fig 219, are provided and used in soft or loose soils The sampler is operated by means of the California Drilling Rig, Fig 56, and is forced into the soil by a heavy drop hammer It has been used without casing to depths of 150 ft and to 250 ft with casing in the upper part of the bore hole The sampler has been used in all types of soils and even in soft rock

Porter piston samplers have been used extensively in California and other Western States since 1933 and caused a great improvement in quality of samples and a reduction of costs of detailed exploration in comparison with methods used before that time. The samplers are simpler in both construction and operation than samplers with stationary piston, but they retain some of the disadvantages of open drive samplers. When the piston is retracted, the sampler will act as an open sampler during actual sampling, and the large area ratio may cause excess soil to enter the sampler. Furthermore, establishment of atmospheric pressure in the sampler by retraction of the piston corresponds to unwatering a bore hole and may cause failure and flow of soft or cohesionless soils into the sampler. On the other hand, when the sampling tube is filled with water on account of leakage through the joints, very large hydrostatic pressures may be created over the sample during the drive since the effective area of the inside vents of necessity is very small. Such excess hydrostatic pressures will hinder entrance of soil and may cause downward deflection and stretching of the soil before it enters the sampler. A few experiments were made with the 1-in. sampler during the research by the Committee on Sampling and Testing, and good results were obtained; see Fig. 107. However, these experiments were made very close to the ground surface and above ground-water level, and it is not yet known to what extent the above mentioned, theoretically possible sources of disturbance may affect samples taken in deep bore holes and below the ground-water level.



FORT PECK DISTRICT CORPS OF ENGINEERS

SAMPLER WITH FREE PISTON

FIG. 220

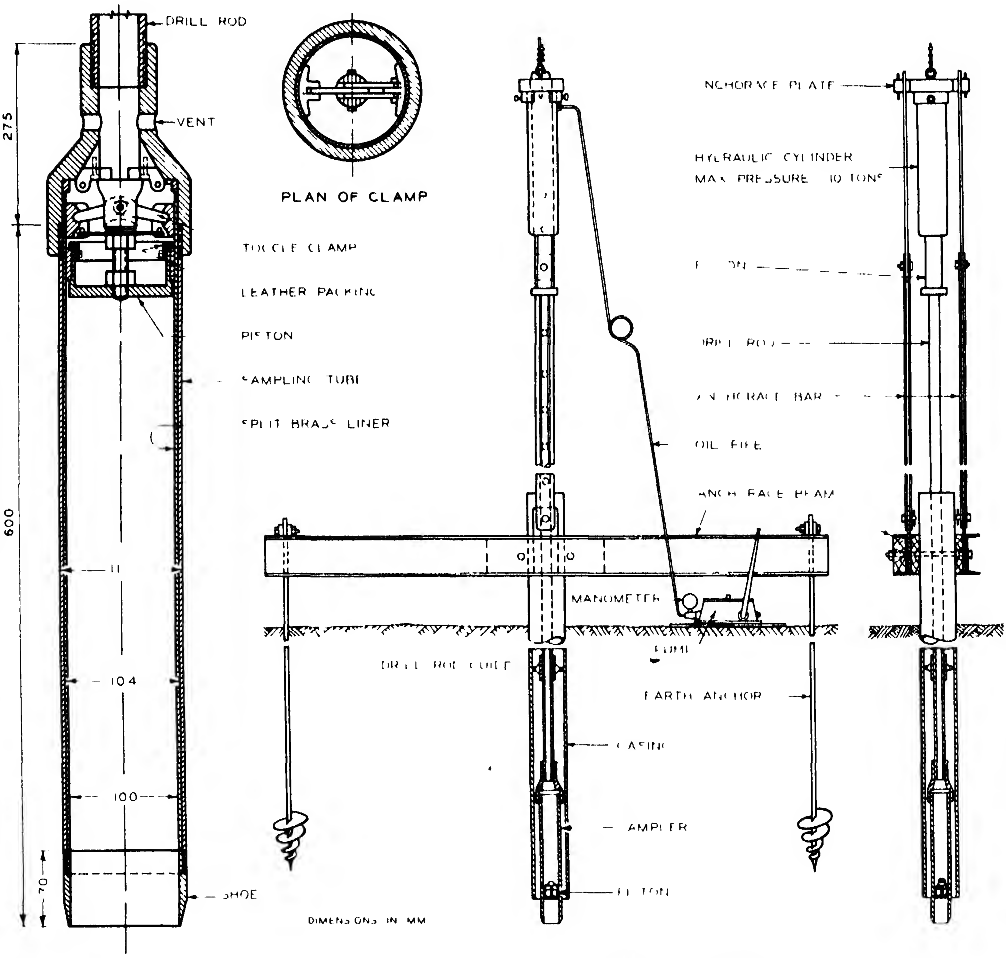
10.7 Drive Samplers with Free Piston

Very material simplification in the operation of piston samplers can be obtained when the piston is neither retracted nor held stationary but is free to move upward with respect to the sampling tube during the actual sampling.

A simple sampler with semi-free piston and for use at relatively shallow depths is shown diagrammatically in Fig. 220. This sampler was designed by the **Fort Peck District**, Corps of Engineers, (109, 110) and is primarily intended for obtaining samples from soft core sections of hydraulic fill dams. The piston rod with the piston in its lower position is clamped to the drill rod during the lowering or pushing of the sampler to sampling depth. The clamp is then released and the sampler pushed into the soil while a slight upward

pull is exerted on the piston rod The piston rod is again clamped to the drill rod, the sampler is withdrawn, and the sample pushed out of the tubing by means of the piston In another design the sampler is provided with a shoe and a brass liner

The piston rod is entirely eliminated in a sampler, Fig 221, designed by **Ehrenberg** (510) and used extensively in Germany since 1928 The hollow piston is free to move upward in the sampling tube, but any downward movement is prevented by a simple toggle arrangement which can be released after removing the sampler head The sampler has a split brass liner with the two parts held together



DETAILS OF SAMPLER

GENERAL JACKING AND SAMPLING ARRANGEMENT

J EHRENBERG DIE BAUTECHNIK 1935 P 303

EHRENBERG FREE PISTON SAMPLER

FIG 221

by thin rings at top and bottom, see Fig. 332E. Since the piston is not clamped in its lower position, this sampler cannot be forced through soft disturbed soil at the bottom of the hole before starting the actual sampling In spite of the outside vents, there is also danger of a premature upward movement of the piston when the sampler

is lowered rapidly into a bore hole filled with water The sampler is primarily intended for use in cased and dewatered bore holes, and the principal function of the piston is that of a very efficient check valve. The sampler is forced into the soil by means of a hydraulic ram, which is attached to anchorage beams and earth anchors by means of adjustable steel bars.

A sampler with stationary piston can be used as a sampler with free piston simply by not clamping the piston rod to the casing or ground during the drive. The corresponding reduction in operating time is relatively small; the weight of the piston rod will increase the pressure on top of the sample, and the principal advantage of this method of operation is that the length of the sample can be determined at any time during the drive. Complete specific recovery ratio curves can be obtained by attaching a recording mechanism to the piston rod and drill rod, Fig. 98D, but the piston rod extensions should be as light as possible when used for this specific purpose

A considerable reduction in operating time and also in pressure on top of the sample can be obtained by eliminating the piston rod extensions and clamping the piston rod proper, with the piston in its lower position, in such a manner that the clamp can be released at the desired sampling depth by means of a wire line and overshot, a drop weight, or by rotation of the drill rod A sampler of this type, designed by **S. J. Meijn** and described by **Huizinga (218)**, is shown in Fig 222 The piston is held in its lower position by a collar in the sampler head and two lugs on the short piston rod A quarter turn of the piston rod will place the lugs in line with grooves in the inside collar so that the piston now is free to move upward Rotation of the piston rod is prevented by means of wings on the protruding part of the piston Downward movement of the piston during withdrawal is prevented by a ball cone clamp, which after the withdrawal is released by inverting the sampler and giving the piston rod a sharp blow. The dimensions of the sampler are not given in the above mentioned reference, but the inside diameter is reported to be between 1 and 1-1/2 in , and the sampler is primarily used in reconnaissance explorations

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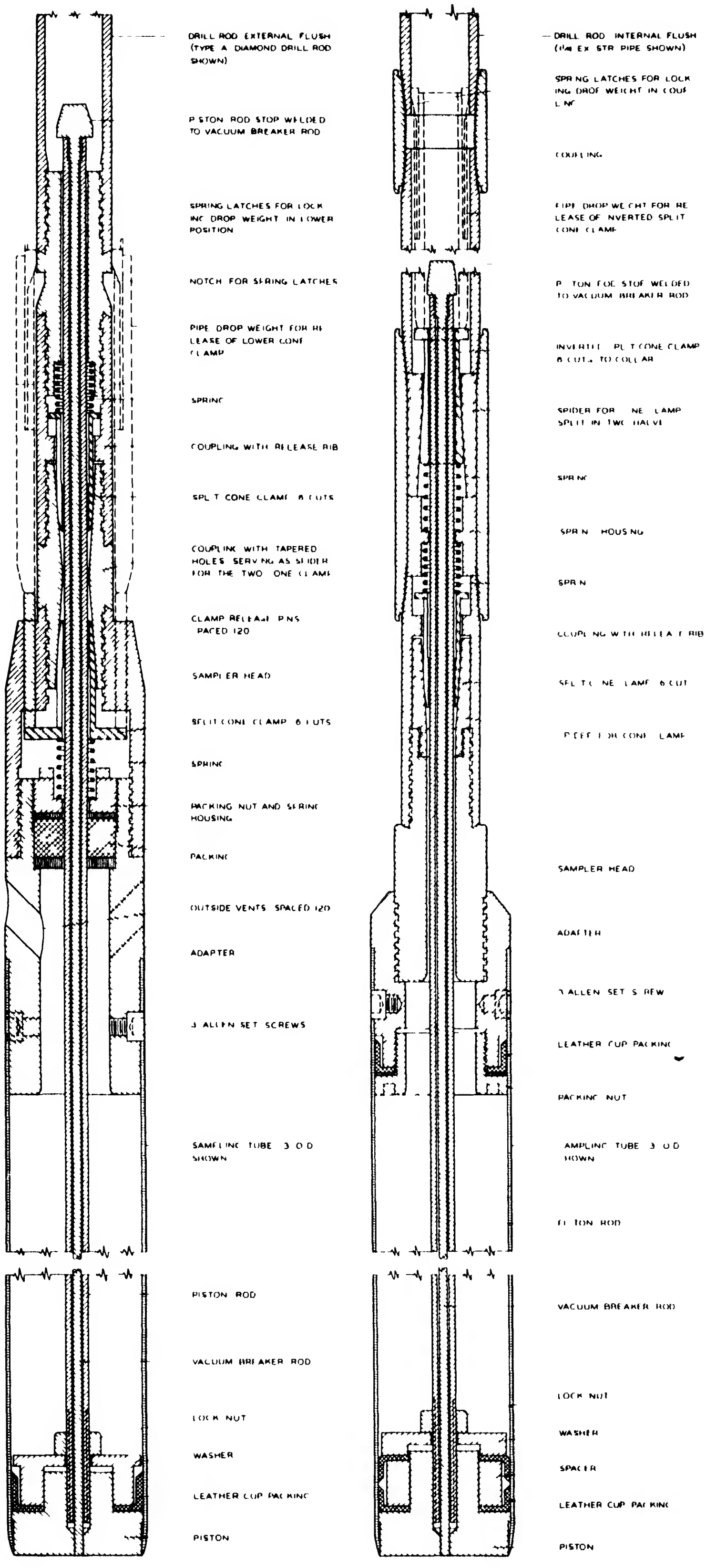
MEIJN FREE PISTON SAMPLER

FIG 222

Several tentative designs of samplers with free piston were made during the

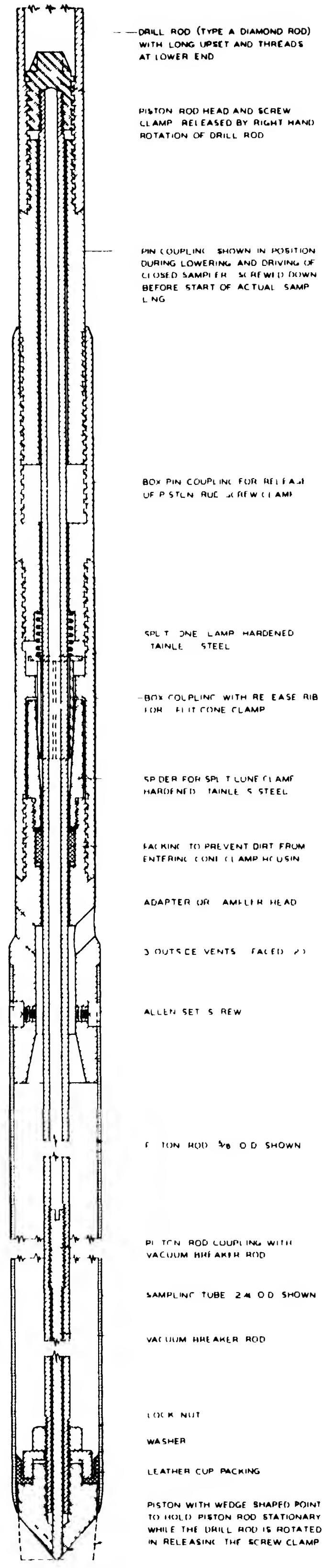


A - OUTSIDE RELEASE AND VENTS

B - INSIDE RELEASE AND VENTS

SAMPLERS WITH FREE PISTON AND DOUBLE CONE CLAMPS

FIG 223



THIN-WALL SAMPLER WITH FREE PISTON

SPLIT CONE AND SCREW CLAMPS

FIG 224

942 MJH

research by the Committee on Sampling and Testing. A couple of these designs, with the piston held in its lower position by means of an inverted cone clamp, are shown in Fig. 223A and B. When external flush drill rods are used, Fig 223A, the inverted cone clamp may be placed below the regular clamp and released by means of pins through the sampler head and an external annular drop weight The weight is provided with latches, which engage a groove in the drill rod and lock the weight in its lower position, thereby preventing re-activation of the inverted clamp With internal flush drill rods, Fig 223B, the inverted cone clamp is placed above the regular clamp and released by an internal drop weight The sampler shown has inside venting, in which case water should be prevented from entering the space above the piston Packing is therefore placed between the tubing and the sampler head, and the piston is provided with double acting packing The advantages and disadvantages of outside and inside vents are discussed at the end of this section

The design of another sampler, which in several respects is similar to the Meijn sampler although independently developed, is shown in Fig 224. The piston is here held in its lower position by means of a screw clamp on top of the short piston rod When the screw clamp is engaged during lowering and driving to sampling depth, the special coupling below the clamp is partially unscrewed, but the threads of the pin are protected by a sleeve extension of the box On reaching sampling depth, the screw clamp can be released by rotation of the drill rod, provided the sampler is driven so far into the soil that outside friction and the wedge-shaped piston can prevent rotation of the latter and of the sampling tube A downward movement of the piston during withdrawal is prevented by a split cone clamp. It is possible that a ball cone clamp of the type shown in Fig 207 and 215 may offer less resistance to an upward movement of the piston and therefore be preferable to a split cone clamp The sampler is shown with outside vents, but it can, of course, also be built with inside vents, in which case the piston should have double acting packing, and packing should be provided between the tubing and the sampler head For use in very stiff or dense soils and in reconnaissance explorations, the thin-wall sampling tube may be replaced with a strong working barrel, a detachable shoe, and a thin-wall liner

Samplers with free piston of the types shown in Fig 222-224 are nearly as easy to operate as open drive samplers and have the advantages that (1) they can be used for displacement boring or pushed through sludge and disturbed soil before the actual sampling is started, (2) the total penetration, sample length, and recovery ratio can be determined accurately, and (3) the piston is much more effective than an ordinary check valve, and the danger of losing the sample during withdrawal is decreased On the other hand, entrance of excess soil is possible, in contrast to samplers with stationary piston, and when the samplers have outside vents, the pressure on top of the sample will be greater and the safe depth of penetration smaller than for a corresponding open drive sampler

When a free piston sampler is provided with inside vents and used in a bore hole filled with water, and when leakage through the joints is prevented and atmospheric

pressure maintained over the piston, the pressure on top of the sample may be smaller than in a corresponding open drive sampler. In such a case entrance of soil into the sampler is facilitated and longer samples can be obtained than with an open drive sampler of a free piston sampler with outside vents In deep, water-filled bore holes, the pressure differential caused by maintaining atmospheric pressure over the piston may even be sufficient to cause failure and flow of soft soil into the sampler, once the clamp holding the piston in its lower position is released On the other hand, the effective area of the inside vents is of necessity so small that large hydrostatic pressures may be created over the piston during the driving and transmitted to the sample when the space over the piston is filled with water on account of leakage through the drill rod joints. Entrance of soil is then impeded, and only short samples will be obtained of soft soils In general, undisturbed samples of soft and sticky soils should be obtained by means of a sampler with a stationary and not a free piston

Other samplers with free piston, which may be used to advantage in surface and control sampling, are described in Section 15 4.

CHAPTER 11
SPECIAL METHODS AND EQUIPMENT FOR PREVENTING LOSS OF SAMPLES

11.1 General

In order to retain the sample in the sampler, the sum of the pressure by air or water on the bottom of the sample and of the friction and adhesion between sample and sampler must be greater than the sum of the weight of the sample, the total pressure on top of the sample, and the force required to separate the sample from the subsoil The principal causes of loss of samples are the following

(1) Excessive air or water pressure on top of the sample, caused by fluid in the drill rod, air between the top of the sample and a check valve, and leakage around check valves or pistons, through joints in the liner, or between the tubing and the sampler head.

(2) Insufficient development of friction and adhesion between sample and sampling tube or liner, caused by excessive inside clearance and/or remolding of soil close to the surface of the sample

(3) Insufficient length of sample to transmit the required total forces from the sampling tube or liner to the sample

(4) Great tensile strength of the soil, or adhesion between the subsoil and bottom of a sample cut with a snare wire

(5) Development of a partial vacuum or a decrease in hydrostatic pressure below the sample

(6) Progressive internal failure of soil with little or no cohesion, caused by its dead weight and/or a downward flow of fluid through the sample, or due to turbulence in and erosion by fluid below the sampler during rapid withdrawal

(7) Excessive acceleration and speed, shocks and vibrations during withdrawal of the sampler

The total friction and adhesion between sample and sampler increases with increasing length of sample, whereas the difference between the forces acting on the top and bottom of the sample is practically independent of the length but increases with increasing cross-sectional area or with the square of the diameter of the sample Likewise, the danger of progressive internal failure of the soil increases rapidly with increasing diameter of the sample In general, the difficulties in retaining the sample during withdrawal decrease with increasing length and increase with increasing diameter of the sample

When normal precautions as outlined in Section 4 14 are observed, samples up to 2 in and often 3 in in diameter can usually be retained without difficulty, at least when samplers with a free or stationary piston are used Examples of samples of extremely soft soils and loose cohesionless soils, obtained in normal sampling operations by means of a 2-in sampler with stationary piston, are shown in Fig 225 and 226 The sample section shown in Fig 225 was cut from the lower and not the upper end of a 42-in long sample of semi-liquid harbor mud, so soft that the sample section collapsed under its own weight when removed from the tubing The sample of loose sand was taken at the bottom of a bore hole filled with water and hence without favorable influence of capillary pressures and apparent cohesion

2" SAMPLE OF SEMI-LIQUID MUD
FIG. 225

2" SAMPLE OF LOOSE SAND
FIG. 226

When difficulties are encountered in retaining samples of small diameter, it is generally sufficient to make minor modifications in the normal sampling procedure and equipment Such modifications may also suffice to retain large-diameter samples of many soils, but special methods and equipment are often required to prevent loss of large-diameter samples of soft or cohesionless soils

11.2 Minor Modifications in Sampling Procedure and Equipment

An outline of various minor modifications of the normal sampling procedure and equipment in order to prevent loss of samples is presented in Section 4 15 and Table 7 For reasons of continuity, this outline is repeated in this section, and the various suggestions are discussed in greater detail Before such modifications are made, the sampler should be thoroughly inspected to insure that its various parts, especially the check valve or piston and piston rod clamping unit, are in proper condition, and defective parts should be cleaned, repaired, or replaced as may be required

(1) **Defective or ineffective check valves.-** Ball, cone, and disk type check valves are easily fouled by dirt, especially when the valve seat is depressed Greater efficiency and reliability can often be obtained by use of a raised valve seat Piston type check valves, Fig 182 and 183, and cock valves, Fig 200, are less susceptible to fouling than other types However, when the sampler is used in a dry bore hole and there is air over the sample, any type of check valve is inefficient, since a large

downward movement of the sample and increase in space between the top of the sample and the check valve then is required to produce an appreciable decrease in pressure over the sample This applies also to a sampler with retracted piston A free or stationary piston with proper packing is much more efficient in reducing pressure over the sample than a retracted piston or any type of check valve.

(2) **Use of vacuum connections.-** Pressure over the sample can be decreased and loss of samples often prevented by supplementing or replacing check valves with a rubber hose connecting the sampler head to a vacuum pump at the ground surface. The method can be used without detrimental effects when the sample consists of fairly stiff and impervious soils, but it may cause disturbance of samples of cohesionless or very soft soils An arbitrary reduction of the pressure over the sample may cause an excessive upward flow of water or air through samples of porous soils, piping along the surface of the sample, formation of a channel through the center of samples of very soft soils, and partial liquefaction of cohesionless soils Even when the top of the sample is supported by a filter or porous plate, an excessive upward flow of water may remove some of the fine constituents of the soil, and a flow of air may, in addition, remove some of the water in the sample

(3) **Leakage through joints in sampling tubes and liners.-** Leakage through the joint between a thin-wall sampling tube and the adapter, between the top of a liner and the sampler head, and through the joints in sectionalized liners may decrease or destroy the effectiveness of check valves and pistons and cause loss of samples, especially when the sample consists of porous soil or contains strata or seams of such soil Sealing of the joint between a thin-wall sampling tube and the adapter and between a continuous liner and the sampler head is advisable when pressure over the sample is controlled by a check valve or a retracted piston but is unnecessary when a free or stationary piston is used Leakage through joints in a sectionalized liner may cause loss of the sample or the lower part of a sample whether a check valve or a free or a stationary piston is used

The greatest danger of loss occurs at the start of the withdrawal and until the cutting edge of the sampler is above the original bottom of the hole During this period leakage has its principal source in a flow through the joint between the top liner section and the sampler head, and loss of samples can often be prevented by sealing this joint After the sampler is out of the soil, water or air may enter the space between the liner and sampler barrel through the joint between the bottom liner section and the sampler shoe, and the consequent leakage through joints between liner sections may cause loss of the sample. In such a case the lower joint should also be sealed or the sectionalized liner should be replaced with a continuous liner A practical and reliable method for sealing the joints between liner sections of thin-wall tubing has not yet been developed In an emergency and when there is sufficient clearance between the liner and the sampler barrel, the joints may be sealed with two or three layers of scotch cellulose tape.

(4) **Increase of rest period.-** An increase in length of the rest period between

completion of the drive and start of the withdrawal will in many cases increase the adhesion and friction between the sample and the tube and also increase the strength of the thin layer of disturbed soil at the surface of the sample This applies especially to soils which are very sensitive to remolding, and the increase in strength of the disturbed surface layer is in part caused by dissipation of excess pore-water pressures and consequent consolidation and in part by thixotropic processes On the other hand, an excessively long rest period may permit appreciable consolidation or swelling of the sample as a whole to take place It may also cause such an increase in outside friction and adhesion that the sampler cannot be rotated without breaking the joints in the drill rod or the joint between the adapter and a thin-wall sampling tube, or twisting and breaking of the tube itself

(5) Decrease of the inside clearance.- A decrease of the inside clearance is often effective in preventing loss of samples of fairly stiff or dense soils However, the inside clearance should not be eliminated or decreased to such an extent that the safe depth of penetration is reduced materially or the lower part of the sample is seriously disturbed

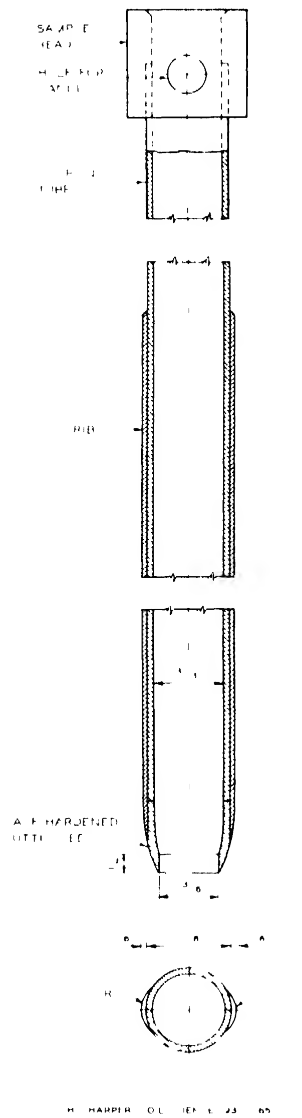
A decrease of the inside clearance is seldom effective in preventing loss of samples of very soft, sticky, or loose soils, since these soils slump and expand laterally during the rest period until full contact with the wall of the sampler is established In this case a decrease of the inside clearance may merely cause the inside friction and adhesion to become more active during the drive and may thereby decrease the length of the sample without a corresponding increase in intensity of the retaining forces during withdrawal, and the result may possibly be a reduction of the total friction and adhesion

(6) Increased length of sample and overdriving.- Short samples are often lost because the total inside friction and adhesion is insufficient to transmit the forces required to separate the sample from the subsoil by a direct pull or by combined pull and rotation An increase in length of the sampler and sample may in such cases be sufficient to prevent loss of the sample

Actual overdriving or a penetration considerably in excess of the safe depth of penetration is one of the oldest and most effective methods for preventing loss of samples of cohesionless or partially saturated soils It causes compaction of the samples and increases the inside wall friction and the strength of the soil However, overdriving also causes disturbance of the soil, especially in the lower part of the sample, and it should be used only in emergency and not when undisturbed samples are required Particular caution should be exercised in overdriving a sampler with a stationary piston, since the consequent creation of a void over the sample and an upward flow of water through the sample may cause piping, partial liquefaction, and serious disturbance of the soil When it is necessary to overdrive a sampler with a stationary piston to prevent loss of the sample, and when compaction of the soil can be tolerated, the surface clamps holding the piston rod stationary should be released after reaching the safe penetration During the actual overdriving the

piston will then act as a free piston and thereby increase the compaction and prevent formation of a void over the sample

(7) **Use of a cutting wire.-** Loss of samples more than 3 in in diameter and consisting of tough soils can often be prevented by cutting the sample free from the subsoil by means of a wire loop in the sampler shoe, especially when the sample is very short or, conversely, when the depth of penetration is so great that the sampler cannot be rotated at the start of the withdrawal The use of a cutting wire is ineffective when the soil is soft and sticky, since the adhesion between the surface of the cut may be nearly equal to the original tensile strength of the soil Samples less than 3 in in diameter and the majority of larger samples can be retained without the use of a cutting wire, but the actual cutting of the sample may reduce the stresses transmitted to and the degree of disturbance of the lower part of the sample during the first part of the withdrawal operation The sample may also be cut free by means of inverted core springs, which also serve to support the sample Samplers with such springs are described in Sections 11 5 and 11 7



SOIL SAMPLER BY HARPER
FIG 227

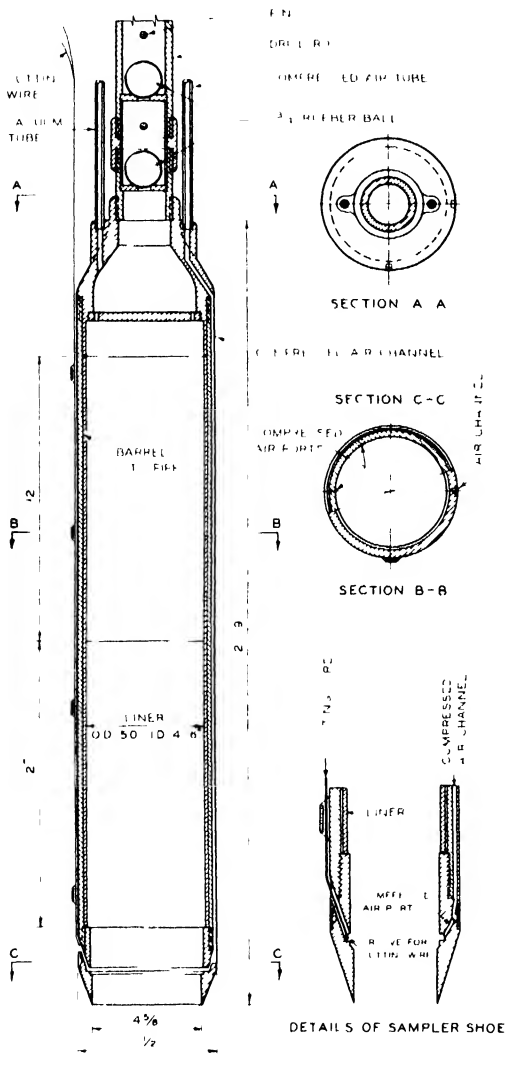
11.3 Maintenance of Pressure below the Sample

Preventing formation of a vacuum and maintenance or increase of pressure below the sample will often be sufficient to retain samples of soils with some cohesion, but loss of samples of loose, saturated, cohesionless soils cannot always be prevented by this method

One of the first attempts to prevent formation of a vacuum below the sample was made by **Harper (707),** who provided his sampling tube, Fig 227, with small exterior ribs, so that an annular space is formed around the sampler when it is rotated prior to withdrawal A similar sampler has been designed by **Myers** and described by **Converse (309).** This method of admitting air or water to the bottom of the sampler is fairly reliable when the soil is firm to stiff, but the annular space between the sampler and surrounding soil tends to close up in soft soils and in saturated, loose, cohesionless soils It may also be difficult to rotate a long sampler of large diameter without overstraining the joints of the drill rod

Water or air passages from the top to the bottom of the sampler may be provided in the sampler itself **Piggot (725)** procured such passages by placing lands between the liner and outer barrel, Fig 259 This method

has the disadvantage that it causes a large increase in the area ratio, and the area of the water passages is not large enough to prevent a material decrease in the hydrostatic pressure below the sampler when it is operated under water and is withdrawn at normal speed



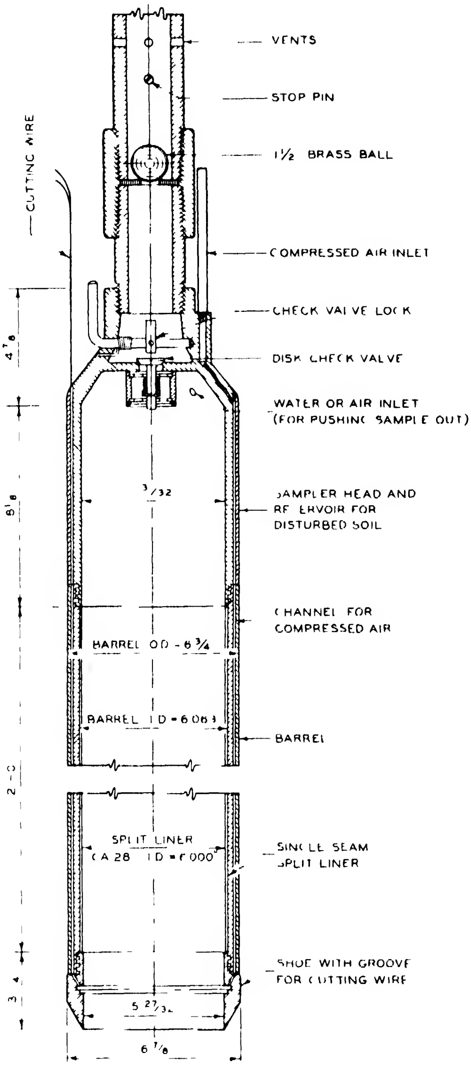
H A MOHR EXPLORATION OF SOIL CONDITIONS HARVARD 1937

SAMPLER BY CASAGRANDE-MOHR-RUTLEDGE
FIG 228

The above mentioned difficulties can be eliminated and the required area of the passages decreased by use of compressed air A sampler with provisions for injection of compressed air below the sample and also for maintenance of a partial vacuum above the sample was first designed by **Casagrande - Mohr - Rutledge** (341, 1st ed 1937) and is shown in Fig 228. The compressed air passage consists of a small groove, which is covered with a metal strip and leads to the sampler shoe The perforated plate above the liner serves to prevent soil from entering the sampler head and fouling the vacuum connection and the double ball check valve The sampler has been used with fair success but was found to be too short, and it was later replaced with the Mohr sampler, Fig 239, which is provided with both flap valves and channels for compressed air

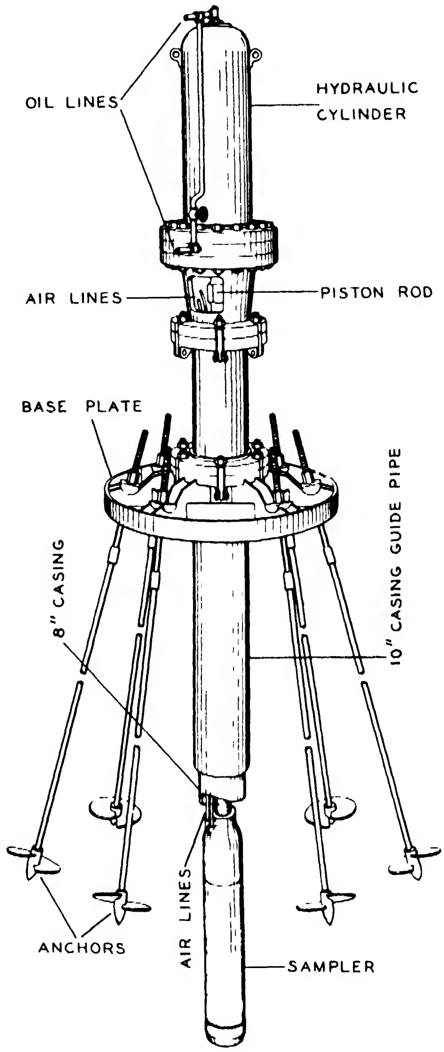
A similar but larger sampler was later designed by the **Missouri River Division,** Corps of Engineers (111, 112) -- see also **Slichter (549).** The sampler, Fig 229, has an inside diameter of 6 in and a single seam, split liner of 28-gage sheet metal It has both a ball and a disk check valve, and the latter can be locked in closed position by means of a lever, which makes it possible to use compressed air to push the liner and sample out of the barrel. Cleaning of the bore hole before sampling is eliminated in this case by providing a large reservoir for disturbed soil above the liner The exploration then consists of only two steps, the actual sampling and the advance of the casing The sampler is forced into the soil by means of a large hydraulic jack, fastened to a base plate and four to six earth anchors, Fig 103 and 230 The hydraulic jack is double-acting and is also used for withdrawing the sampler and for advancing and pulling the casing Vibrations during advance of the

casing are thereby avoided, and one source of disturbance of the soil to be sampled is eliminated The penetration resistance of this sampler when used in various types



F B SLICHTER ENG NEWS RECORD 1940 VOL 125 P 756

MISSOURI RIVER SAMPLER
FIG 229



F B SLICHTER A NON DISTORTING OIL SAMPLER ENG NEWS RECORD 1941 VOL 125 p 756 757

FIG 230—MISSOURI HYDRAULIC JACK

of soils is given in a table in Section 4 10 The sampler has primarily been used in firm soils, in which it was found to be unnecessary to use either a wire loop to cut the sample free or compressed air to maintain pressure below the sample.

The above mentioned Mohr sampler with compressed air ducts and flap valves is described in Section 11 6, but it may be mentioned here that the **Massena District,** Corps of Engineers, built a sampler of similar design and increased the pressure of air injected below the sample to such an extent that it forced the sampler out of

the soil This method of operation facilitated withdrawal of the sampler and provided additional insurance against loss of the sample

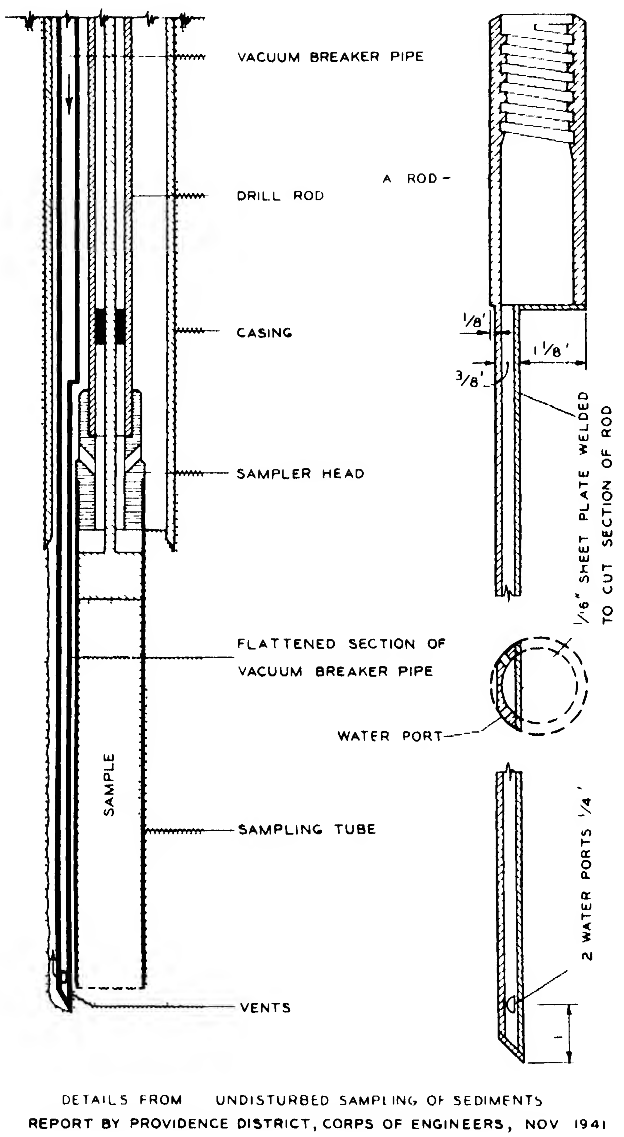


FIG 231 — SEPARATE VACUUM BREAKER PIPE

The above mentioned methods of maintaining pressure below the sample require samplers of special construction and cannot be used with thin-wall samplers A simple method, which can be used with any type of sampler provided there is at least 1/2-in. clearance between sampler and casing, has been developed by the **Providence District,** Corps of Engineers, and described by **Fahlquist (120).** The method consists in forcing a flattened or cut-away pipe down along the sampler after completion of the drive, Fig. 231, and then injecting water or compressed air through this pipe

11.4 Pre-advance and Cleaning of the Casing

Even when compressed air is injected under the sample, normal hydrostatic pressure corresponding to the water level in the bore hole will be established when the sampler is raised above the original bottom of the hole. The lower and currently uncased part of the hole may then cave in before the casing can be advanced. When fairly continuous and undisturbed samples are to be obtained in deposits of very soft soils or loose cohesionless soils, it is advisable to advance and clean the casing to the cutting edge of the sampler before the latter is withdrawn. This operation will also prevent formation of a vacuum below the sampler.

The casing should preferably be advanced by jacking and rotation, if necessary supplemented by jetting along the outside of the casing. The space between the sampler and the casing may be cleaned out by means of a flattened wash pipe. However, when the clearance between sampler and casing is small, it is difficult to move

the pipe around the sampler, and the capacity of a single pipe is small. In this case it is advantageous to use a distributor ring with multiple jets, a jetting ring, or a jetting barrel as shown in Fig. 232 The annular clean-out tool should be lowered into the casing with the sampler, and the distributor ring or barrel adapter will then insure proper centering of the sampler and also limit the stroke, thereby preventing jetting below the sampler. An annular auger with shielded jets, Fig 248, should be used when the depth to which the casing is to be cleaned must be controlled very accurately, see Section 11 8

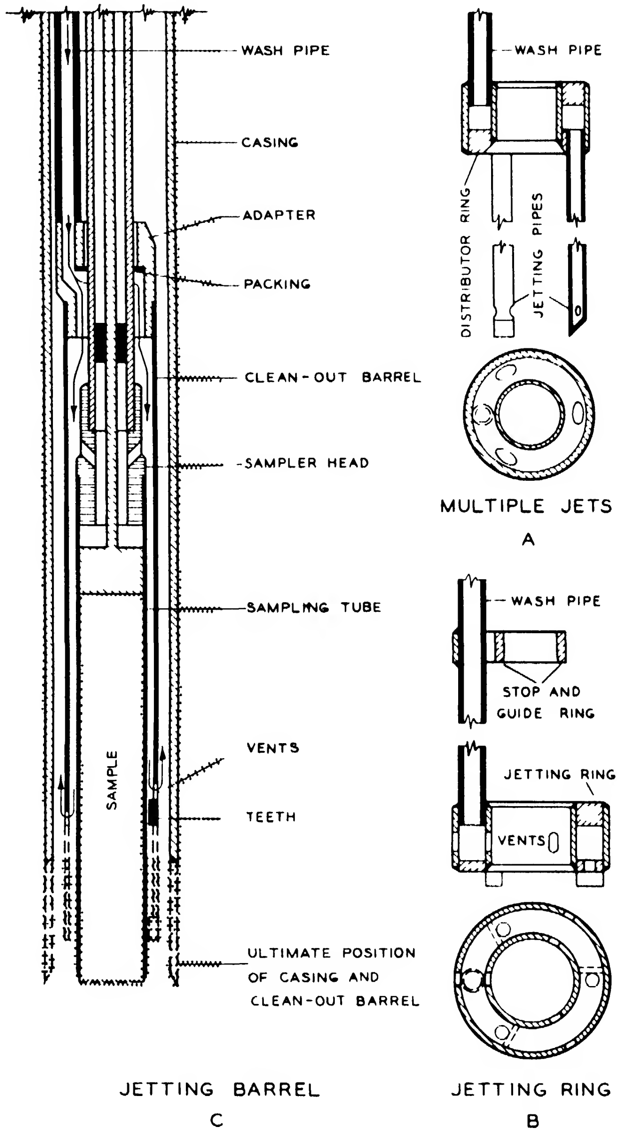


FIG 232—PRE-ADVANCE AND CLEANING OF CASING

11.5 Samplers with Spring or Ribbon Type Core Retainers

Special core retainers are commonly used in core barrels and occasionally in drive samplers. The operation of a sampler with a core retainer is relatively simple, and the retainer may suffice to prevent loss of the sample and thereby eliminate the necessity of cutting the sample free by means of a wire loop and of maintaining pressure below the sample However, unless special precautions are taken in design and construction, core retainers in drive samplers may disturb samples of soft or loose soils, and they always cause an undesirable increase in wall thickness of the sampler shoe and area ratio of the sampler

One of the simplest and most frequently used core retainers consists of several strips of spring steel or bronze, which are fastened to a base ring and placed in or above the sampler shoe, Fig. 233A to F. Such a core retainer is called a spring, finger, or basket type retainer A few relatively stiff springs, A and B, are used in stiff or dense soils, but they prevent entrance of soft soils and fine-grained, cohesionless soils and permit such soils to pass through the spaces between the

springs A larger number of thin and flexible springs is therefore used in core retainers for soft soils and fine cohesionless soils, C and D The individual springs are often fastened to the base ring by means of rivets, but the rivet heads may cause additional disturbance of the sample, and it is preferable to attach the springs to the base ring by brazing, welding, or wedging, D and E. Very thin steel springs are easily broken, subject to rust, and require frequent replacement; it is reported that core retainers of spring bronze give longer service.

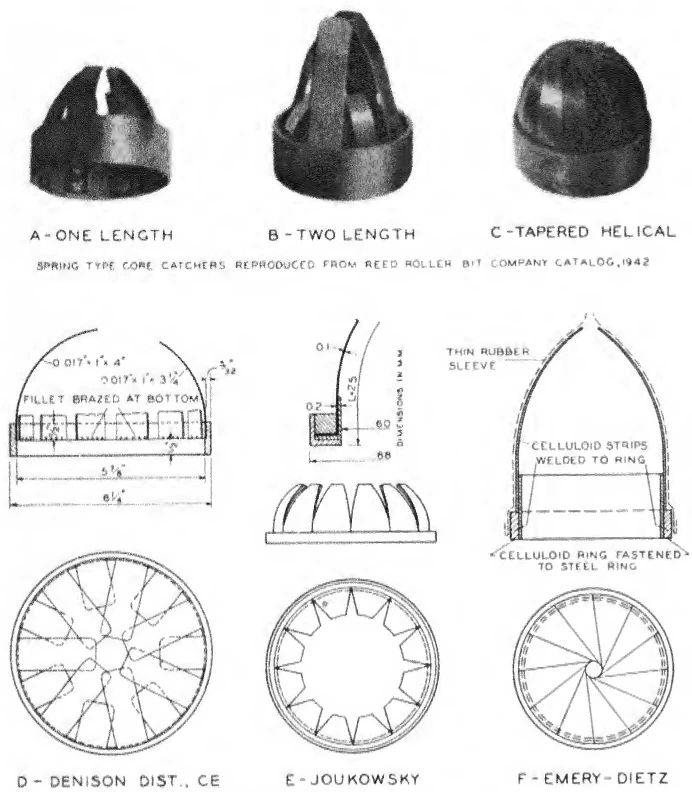
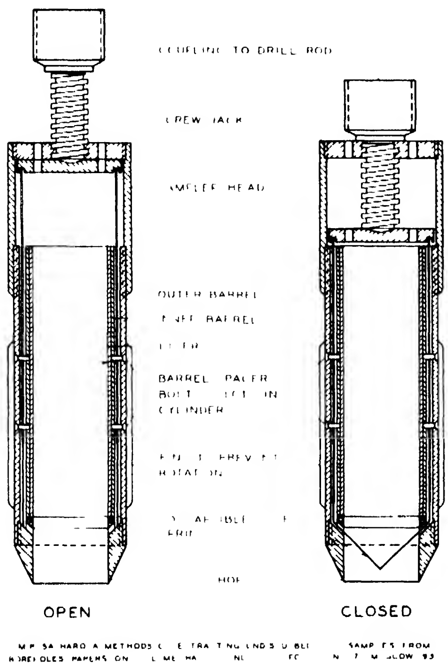


FIG. 233 - SPRING TYPE CORE RETAINERS

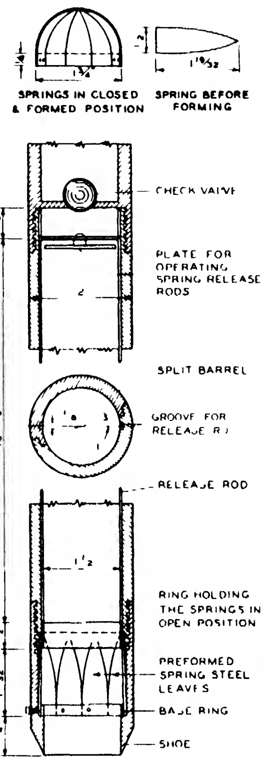
Silt and fine sand may pass through the joints between closely spaced or overlapping springs, and even very thin and flexible springs may obstruct entrance of soft soil and cause disturbance of the sample In an effort to eliminate these disadvantages, **Emery and Dietz (705)** replaced metal springs with celluloid strips, Fig 233F and 255, cemented to a heavier celluloid base ring, which in turn is fastened to a thin steel ring The celluloid strips are covered with a thin rubber sleeve, which aids in starting the inward bending of the strips and closure of the retainer and also seals the joints between the strips It is reported that the combination forms a nearly watertight closure of the barrel Fig 233F is drawn from a small photograph and a brief description, and there may be minor differences between this figure and the actual detailed design

In a sampler designed by **Hammond (524)** and shown in Fig 234, preformed core springs are held in open position by a thin ring This ring is attached to a plate in the sampler head by means of two thin rods, which are concealed in grooves in the sampler walls The springs are released when the sample reaches this plate and forces it, the rods, and the restraining ring upward The resistance to entrance of soil, which otherwise would be exerted by the springs, is thereby decreased, but a slight overdriving of the sampler may be required to insure that the springs are activated, and the protruding edge of the restraining ring and the recesses between the springs may engage the soil and cause disturbance of the sample.

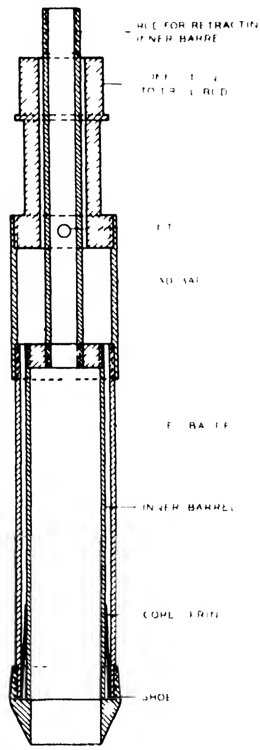
The engineers of the Structural Division of the Russian Federal Institute, **Sacharova** (545, 546), have developed two samplers, Fig. 235 and 236, in which spring type core retainers are concealed between the liner and the sampler barrel Ob-



IVANOFF SAMPLER
INVERTED CORE SPRINGS
FIG 236



HAMMOND SAMPLER
PARTLY CONCEALED SPRINGS
FIG 234

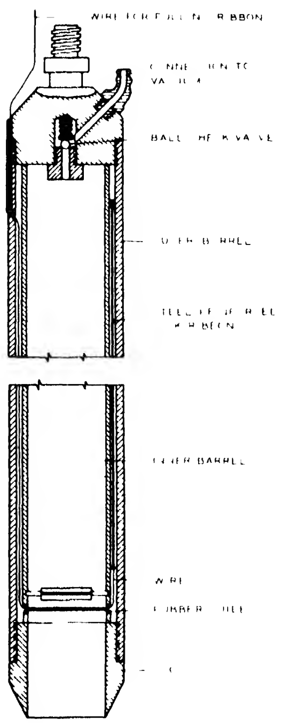


VIOS SAMPLER
CONCEALED CORE SPRINGS
FIG 235

struction to entrance of soil and disturbance of the sample caused by exposed core springs are thereby eliminated, but the over-all wall thickness and the area ratio of the samplers are greatly increased.

In the **Vios** sampler, Fig 235, the liner is attached to a piston with a rod extending to the top of the drill rod Upon completion of the drive, a pull is exerted on the piston rod, and the liner is withdrawn to the sampler head, thereby releasing the core springs. The **Ivanoff** sampler, Fig. 236, has both a liner and a double barrel with the two barrels connected by several spacer bolts. A thin cylinder with slots for the spacer bolts is placed between the two barrels and connected to a piston above the liner. Strips of spring steel are fastened to the lower edge of the cylinder and are forced out through openings in the shoe and in under the sample when the drill rod is rotated and forces the piston down Steel fins are welded to the outer barrel to prevent rotation of the sampler itself. Some difficulties were experienced when fine soils fouled the exposed threads at the lower end of the drill rod, but these threads can easily be protected by a sleeve.

Comparative tests indicated that void ratios of samples of cohesionless soils taken with the **Vios** sampler were slightly larger than those of samples obtained with the **Ivanoff** sampler. This difference in void ratios may be caused by a pull on the sample in a **Vios** sampler during retraction of the liner and a downward movement of the sample to close the core springs Since the **Vios** sampler also required a piston rod, the **Ivanoff** sampler was adopted for general use It is possible that the samples may be partially disturbed on account of the very large area ratio of this sampler

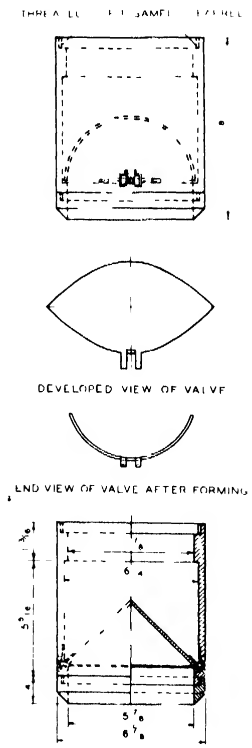


MAZALAN SAMPLER
RIBBON CORE RETAINER
FIG 237

A sampler with a ribbon type core retainer, Fig 237, has been developed in Hungary and described by **Pál Mazalán (153).** The sampler has a split liner with outside ribs which form longitudinal channels between the liner and the barrel. Two steel-reinforced silk ribbons are placed in these channels and connected to wires by means of which they can be pulled across the lower end of the sample. The ribbons cut the sample free and support it during withdrawal It was found difficult to pull the ribbons across samples of gravelly soils, and samples of fine sand were occasionally lost A similar core retainer with thin steel bands instead of silk ribbons has been proposed independently by **B. K. Hough, Jr.**

11.6 Samplers with Valve Type Core Retainers

Core retainers in the form of flap valves, also called doors or leaves, are commonly used in bailers, Fig 35, and in samplers intended only for obtaining representative samples, Fig. 177 and 178. Single, flat flap valves as shown in these figures cannot be fully opened; they restrict the entrance area and cause very serious disturbance of the sample Restriction of the entrance area can be eliminated and disturbance of the sample greatly decreased by use of valves consisting of one or more cylindrical segments or inverted "clam shells" placed in recesses in the walls of the sampler shoe. Such a sampler was built by the **Fort Peck District**, Corps of Engineers (109, 110) and is shown in Fig. 238. The springs at the hinges expedite the closing of the valves, but they also cause the valves to be in closed position at the start of the sampling, and the force required to open the valves hinders entrance of soft soil. This disadvantage has been eliminated in a similar sampler, designed by the **Rock**



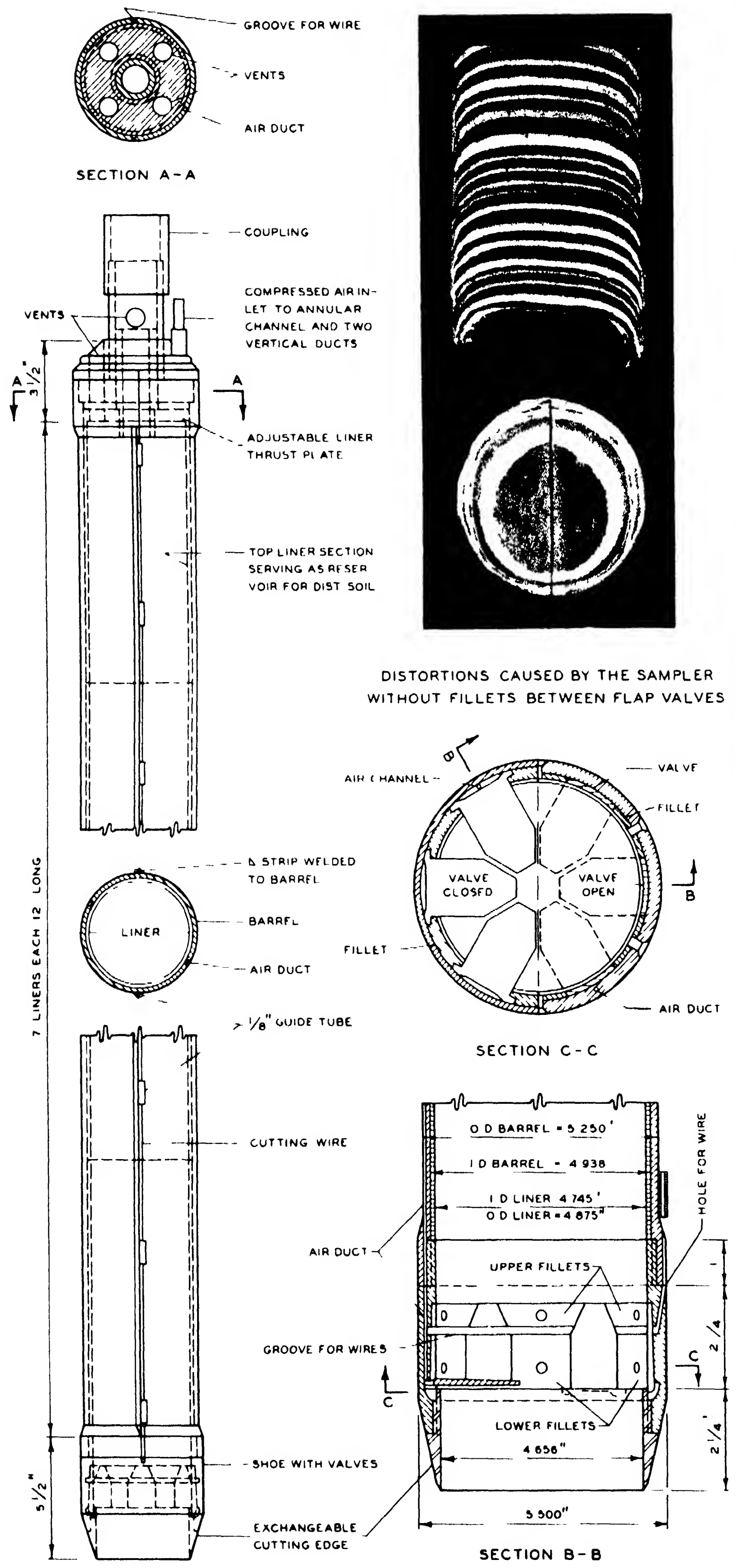
FORT PECK SAMPLER
CLAM SHELL VALVES
FIG 238

Island District, Corps of Engineers, in which the valves are held in open position by means of locking pins. These pins are attached to wires extending to the ground surface, so that the valves can be released before the start of the withdrawal. Valves of the type shown in Fig. 238 practically close the entire opening and are therefore able to retain samples of silt, fine sand, and extremely soft soils.

Several improvements in the design of samplers with flap valves were made in 1937 by **H. A. Mohr.** The original Mohr sampler is described in the Preliminary Report by the Committee on Sampling and Testing (107), and a revised design of 1940 is shown in Fig. 239 The sampler has six segmental flap valves with a hinge arrangement which reduces the required wall thickness of the shoe to a minimum. The valves are activated and the sample cut free from the subsoil by means of two wire loops placed in a groove behind the valves. The sampler is also provided with ducts through which compressed air can be injected behind the valves and below the sample The liner is divided into seven sections, each 12 in. long, of which the upper one or two sections serve as a reservoir for disturbed soil. Ample clearance between the liner and the barrel facilitates insertion and removal of the sections. Proper alignment is obtained by three small knobs on the outside and at each end of a liner section. These knobs are formed by means of the jig shown in Fig. 240. Longitudinal movements and opening of the joints between the sections are prevented by a perforated plate which is pressed against the top liner section by rotating a short section of threaded pipe in the sampler head.

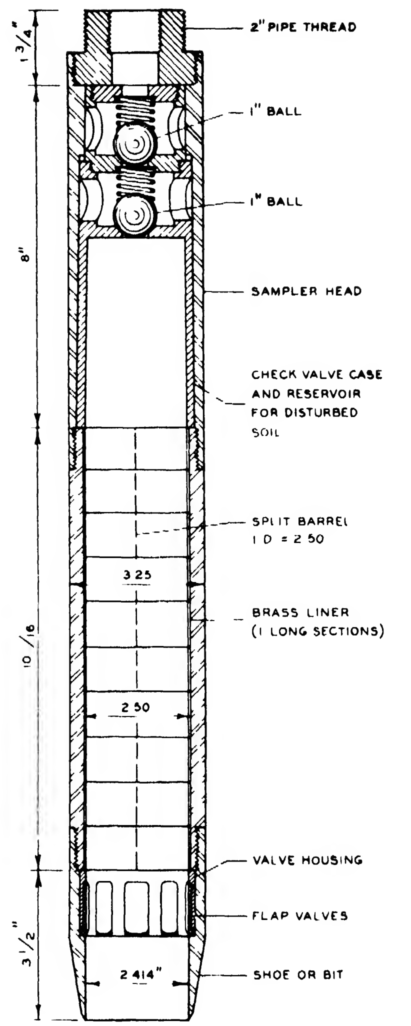
The original Mohr sampler had only four valves, which in closed position covered 40 percent of the area of the sample. It was found that these valves did not give sufficient support for samples of soft soils, which often would be squeezed out between the valves. The length and number of the valves were therefore increased so that they cover two-thirds of the area In the experiments by the Committee on Sampling and Testing it was also found that the lower part of samples of soft soils generally was seriously disturbed, Fig. 107B. Furthermore, the rings in horizontal sections were not circles but approached the form of squares with rounded corners; see photograph in Fig 239. The corners of the rings are opposite the valves, and the maximum distortion therefore occurs in front of the recesses between the valves. It is probable that, as the length of the sample increased, soil was forced into these recesses, and soil entering the sampler then encountered increased resistance in front of the recesses. Fillets were therefore placed in the recesses and a smooth interior produced The inside diameter of the upper fillets is slightly larger than that of the lower fillets in order to prevent the upper edge of the cutting wire groove from engaging the soil.

Subsequent operations with the redesigned sampler indicated that the lower part of the samples was reasonably free of distortions, but the upper part had in some cases specific recovery ratios reaching 130 percent, indicating considerable entrance of excess soil and disturbance during the first part of the drive. The area ratio cannot be reduced much below the current 39 percent when the valves are to



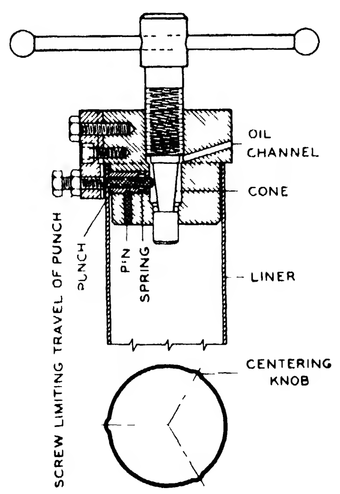
MOHR SAMPLER WITH FLAP VALVES AND AIR DUCTS

FIG 239



DAMES AND MOORE SAMPLER

FIG 241



JIG FOR CENTERING KNOBS

FIG 240

be retained, but entrance of excess soil can be prevented by converting the sampler into one with stationary piston. However, with such a piston sampler and injection of compressed air below the sample, it will generally be possible to retain the sample without the use of flap valves.

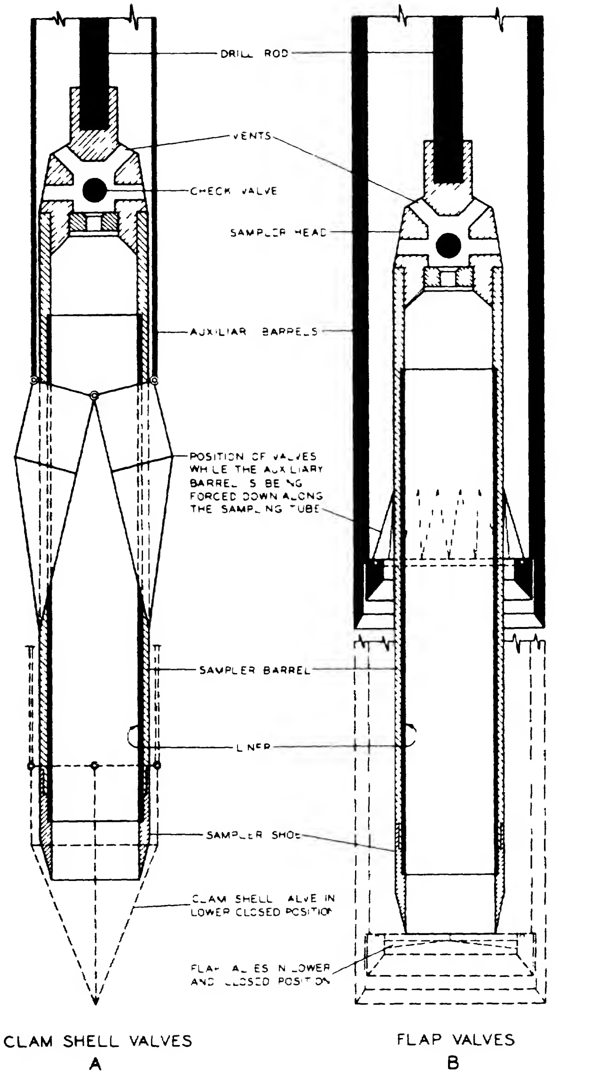
A sampler similar to the Mohr sampler was later designed by **Dames and Moore** (117, 509) and is shown in Fig. 241 The eight valves are placed in a special ring or housing, and a smooth surface is preserved except for a slight offset at the top of the valves Pressure exerted on this offset and friction between the sample and the valves in combination with an eccentric hinge will start the closing of the valves when the sample moves downward. The liner is divided into 1-in. long sections, and consolidation and shear tests are performed without removing the sample from the individual liner sections The sampler is very short and has an area ratio of 81 percent. Since entrance of excess soil was observed in experiments with the Mohr sampler, having an area ratio of 39 percent, it is possible that a greater amount of excess soil will enter the Dames and Moore sampler when it is pushed into soft soil.

11.7 Auxiliary Barrels with Core Retainers

The undesirable increase in wall thickness and area ratio caused by core springs or valves in the sampler shoe can be avoided by placing the core retainers in an auxiliary barrel, which is forced or jetted down along the sampler after completion of the drive. Tentative sketches of two such auxiliary barrels are presented in a review by **Kollbrunner and Langer** (333) and are, with minor modifications, reproduced in Fig. 242. One of these barrels is provided with clam shell valves and the other with multiple flap valves. In both cases a tubing with an internal diameter larger than the outside diameter of the sampler or, at least, larger than the outside diameter of the drill rod couplings must be carried to the ground surface.

A tentative design of a sampler with auxiliary barrel was made during the research by the Committee on Sampling and Testing and is shown in Fig. 243 and 244. It is attempted to eliminate the need of an extra tube or rod to the ground surface by connecting the drill rod to the auxiliary barrel, whereas the sampler through a short rod and a coupling with left-hand threads is attached to the head of the auxiliary barrel After completion of the drive and seating of the piston type check valve, the drill rod is rotated until the connection between the sampler and the auxiliary barrel is disengaged. Water is then pumped through the drill rod, and the auxiliary barrel is forced and jetted down until the top of the flap valves is below the cutting edge of the sampler. The casing is concurrently advanced to the bottom of the sampler The drill rod is then withdrawn, and the flap valves open and retrieve the sampler and sample A piston type sampler can be substituted for the open drive sampler shown in the figure.

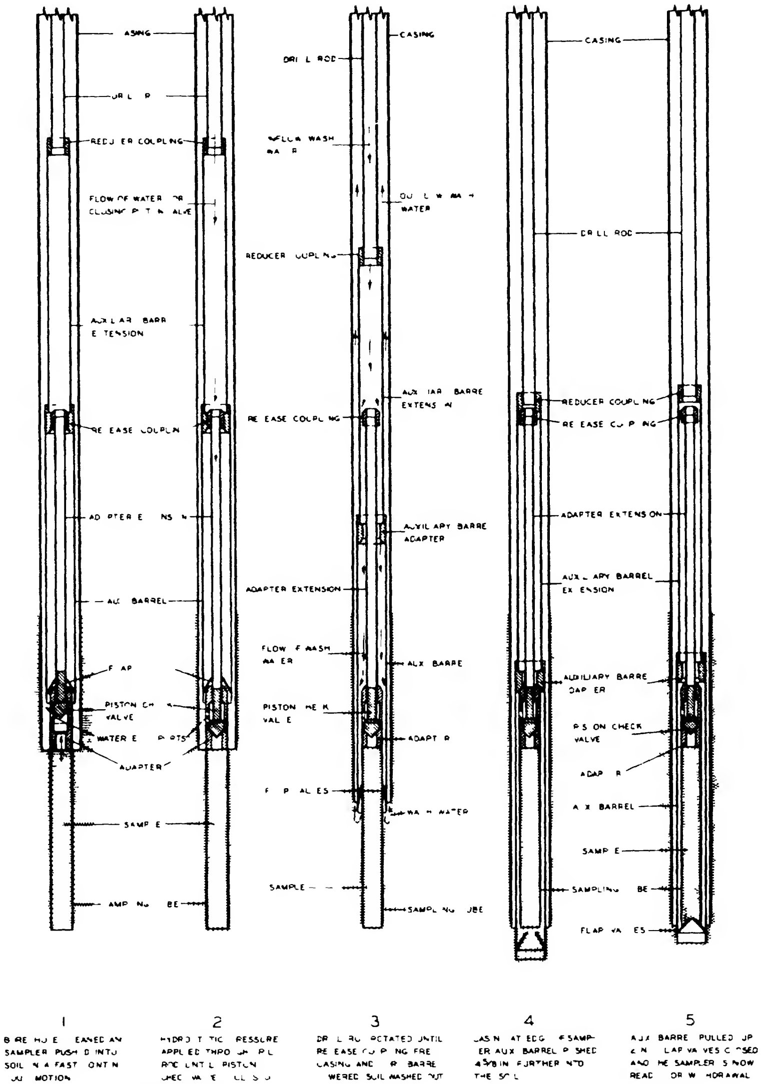
The designs described above are tentative and experiments will undoubtedly



KOLLBRUNNER & LANGER PROBEBELASTUNGEN UND PROBEBOHRUNGEN ZURICH 1939

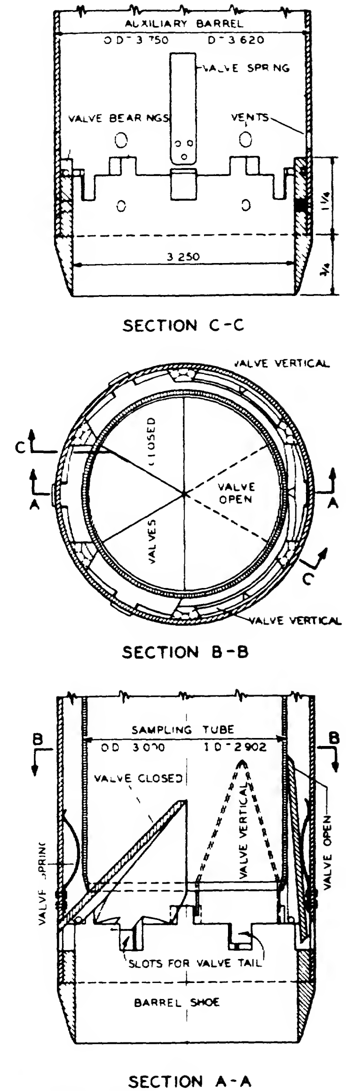
SAMPLERS WITH CORE RETAINER IN SEPARATE BARREL

FIG 242



SAMPLER WITH ATTACHED AUXILIARY BARREL

FIG 243

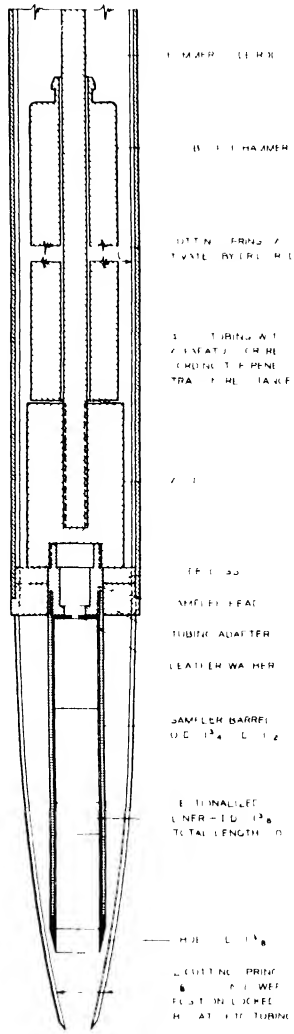


DETAILS OF AUXILIARY BARREL

FIG 244

be required to obtain satisfactory solutions to various problems in design and operation and especially to determine whether the valves close completely when the sampler is operated in cohesionless soils If this requirement can be satisfied, it is possible that a thin-wall sampler with flap valves in an auxiliary barrel may be used to advantage in obtaining samples of saturated silt and fine sand and may be more economical in operation than the freezing method described in the following section

A sampler, Fig 245, which in part utilizes the principle of an auxiliary barrel with core retainer has been developed by **Housel (126, 217)** and used successfully for several years The sampler, with an inside diameter of only 1-1/2 in., is attached to a cartridge or section of 4-in tubing which can slide on the drill rod This cartridge contains a 20-lb hammer, operated by a wire to the ground surface and a trigger which limits the stroke to 34 in , and a mechanism, not shown in the figure, for recording the penetration of the sampler for each blow of the hammer Two long strips or cutting knives of spring steel are attached to the drill rod and slide in grooves in the cartridge Upon completion of the drive, the drill rod is pushed down until the springs attain the position shown in the figure and a trigger locks the drill rod to the cartridge and the sampler The drill rod is then rotated, the springs cut out a conical mass of soil around the sampler, and the entire assembly, including the conical soil mass supported by the springs, can then be withdrawn by means of the drill rod

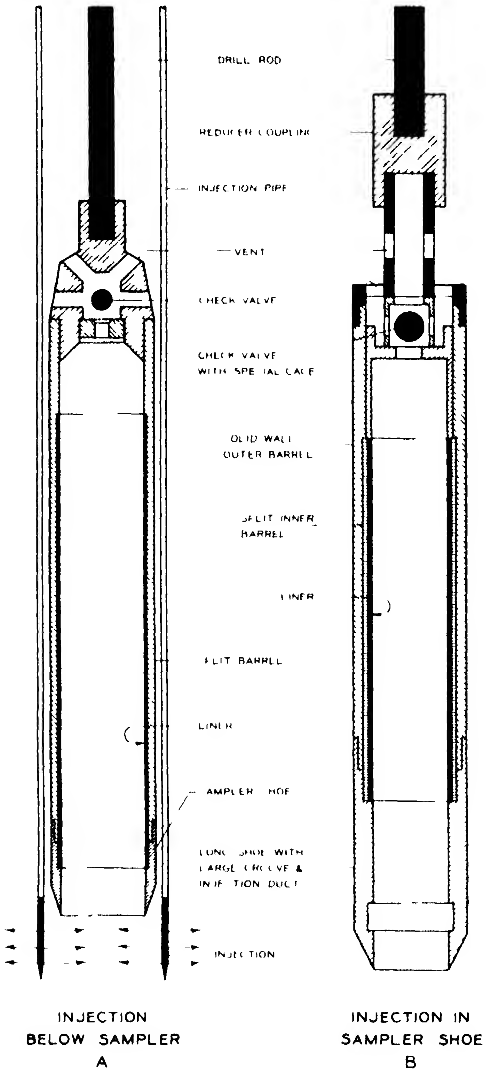


HOUSEL SAMPLER
OUTSIDE CUTTING SPRINGS
FIG 245

11.8 Solidification of the Bottom of the Sample

Although the total friction between the sampler and a sample of cohesionless soil may exceed the sum of the downward forces on the sample, loss during withdrawal may occur on account of progressive internal failure of the soil Gradual loss of the sample because of progressive internal failure is likely to occur when the sample is 3 in or more in diameter, and it cannot always be prevented by decreasing the pressure over and maintaining or increasing the pressure below the sample However, the sample may be retained by imparting a sufficient amount of cohesion to or by solidification of the soil in the lower part of the sample This may be accomplished by impregnation with suitable chemicals, emulsified asphalt, cement grout, clay, etc , or by freezing

Impregnation.- Solidification of the lower part of the sample by injection of chemicals which later form an insoluble gel, for example sodium silicate and calcium chloride, was first attempted by **Ehrenberg (510)**, but the work was not carried beyond the experimental stage, and detailed results have not been published. A brief description of two methods which have been used in practice is given by **Kollbrunner and Langer (333).** In the first of these methods, Fig. 246A, the solidifying chemicals are injected through pipes which are forced down along the sampler until the perforated ends of the pipes are below the cutting edge of the sampler The method has the obvious disadvantage that the solidification is not confined to the lower part of the sample and that a bulb of solidified soil is formed below the sampler This bulb hinders withdrawal of the sampler, and it may remain in the ground and pull the solidified part of the sample out of the sampler and thereby nullify the object of the impregnation



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CHEMICAL SOLIDIFICATION BOTTOM OF SAMPLE

FIG 246

In the second method, Fig 246B, the chemicals are injected through a pipe welded to the outside of the sampler barrel and leading to a groove in the sampler shoe A sampler similar to the one shown in Fig. 197 was used, but it was provided with a longer shoe since the extent of the solidification is difficult to control. The large groove in the shoe serves to distribute the chemicals uniformly and to hold the solidified plug in place in case the soil below the sampler also should become impregnated with the chemicals The sampler has a large area ratio, and the sample may therefore be subject to disturbance.

Impregnation with chemicals, asphalt, grout, etc., can be used only when the soil is very pervious and not in silt and fine sand. Furthermore, foreign substances are introduced into the solidified part of the sample, and this part is unsuitable for laboratory tests unless the foreign substances later are removed. Cement grout and chemicals which form an insoluble gel cannot be removed without serious disturbance of the soil Asphalt may be removed by washing with suitable solvents, but the process is time-consuming and not always complete.

Freezing -- general.- The above mentioned disadvantages of impregnation are to a large extent eliminated when the lower part of the sample is solidified by means of freezing The method of freezing the bottom of the sample was developed by the **Providence District**, Corps of Engineers, with **F. E. Fahlquist (120, 320, 520)** in charge of the experiments and subsequent practical sampling operations and with the writer acting as consultant during the preliminary experiments Additional experiments have recently been performed by the **Waterways Experiment Station,** Corps of Engineers, and the method has been used in extensive subsurface explorations Freezing of the bottom of the sample is the best of currently available methods for obtaining large undisturbed samples through borings in saturated, loose cohesionless soils, and the method will therefore be discussed in some detail.

The casing.- The freezing method is primarily intended for sampling of saturated sand and silt and normally requires a cased bore hole To avoid disturbance of the soil to be sampled, the casing should be kept filled with water and should be advanced without shocks and vibrations, that is, by means of jacking, rotation, or jetting, but not by hammering The advance is facilitated by use of flush jointed casing and by sealing-off overlying strata, of which samples are not required, with casing having a diameter large enough to admit the lower casing and outside pipes for jetting, Fig 247, when the latter are required The **Providence District** used 10-in casing through the upper strata and 6-in flush jointed casing through the strata of which samples were to be taken The **Waterways Experiment Station** uses flush joints for both the 10-in and the 6-in casing, and it was also found that jetting was not required for advance of the lower casing, in which case sufficient clearance for jetting pipes is unnecessary, and the 10-in casing could be replaced with 8-in casing

The sampler.- A slight displacement of cohesionless soils may cause an objectionable disturbance of the soil structure and change in void ratio, and it is essential that the wall thickness and area ratio of the sampler be reduced to the minimum required to prevent excessive deformations or buckling of the tubing Open drive samplers or samplers with a free or stationary piston may be used, but the longest samples and most consistent results have so far been obtained with samplers having a stationary piston However, conclusive experiments with open drive samplers or free piston samplers have not yet been made

The sampler used by the **Waterways Experiment Station** is similar to the one shown in Fig 207, but it has a flat instead of a conical piston in order to facilitate accurate determination of changes in length of the sample The sampling tube proper consists of 3-in. OD tubing, 16 to 18 gage, with a length sufficient to accommodate a 24- to 30-in long sample An inside clearance ratio of 1 0 percent has been used, but it is probable that a considerably smaller clearance is adequate and preferable in many cases.

It is desirable and often necessary that provisions be made for determination of the length of the sample immediately after completion of the drive and for

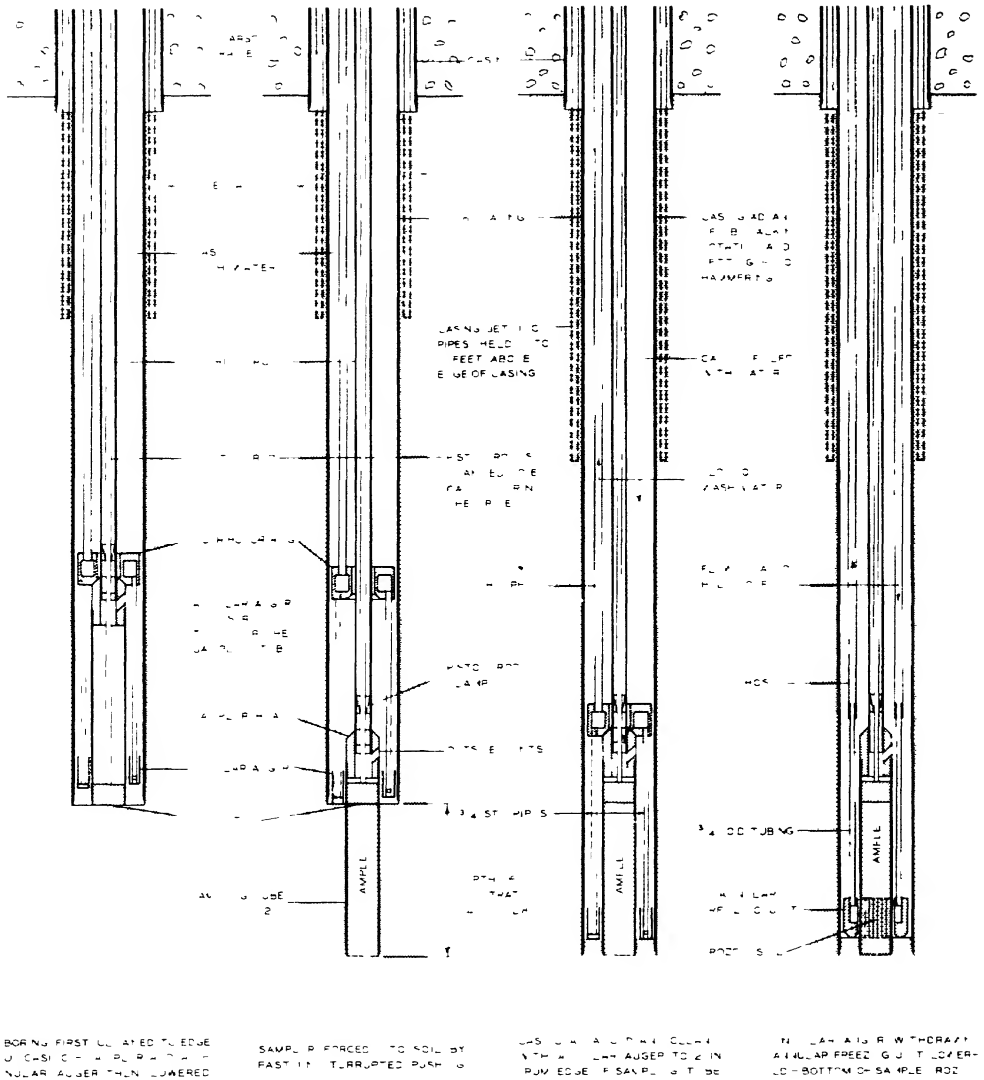
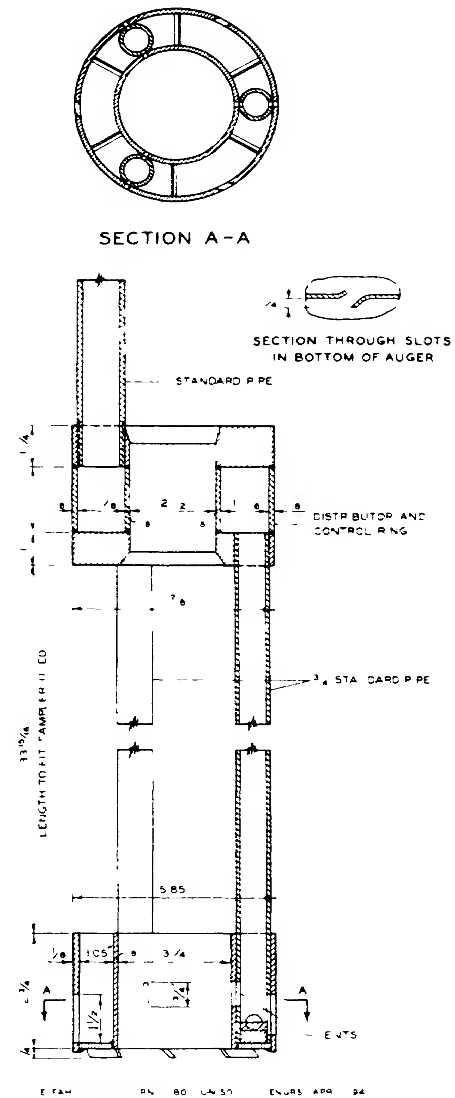


FIG 247 – FREEZING OF BOTTOM OF SAMPLE



ANNULAR CLEAN-OUT AUGER

FIG 248

determination of changes in this length during the subsequent operations This may be accomplished by operating the sampler with the split cone clamp temporarily released, as shown in Fig 208, and by releasing the surface clamps to the piston rod upon completion of the drive The piston is then free to move downward until it is in contact with the top of the sample, and such a downward movement, if any, is equal to the difference between the depth of penetration and the length of the sample This arrangement requires a piston with single-acting packing, so that any water found on top of the sample can flow upward past the piston while the latter moves downward A piston with single-acting packing requires, in turn, outside vents in the sampler head

Another method, which can be used with activated or de-activated cone clamp and whether the piston has single- or double-acting packing, consists in replacing the vacuum breaker rod with a measuring rod extending from the top of the piston rod extensions to a thin plate directly below the piston Movements of the measuring rod indicate changes in length of the sample, and the rod may also be connected to a simple recording device so that complete recovery ratio curves can be obtained Such curves are of material assistance in determining the safe depth of penetration and possible changes in void ratio of the soil during the actual sampling

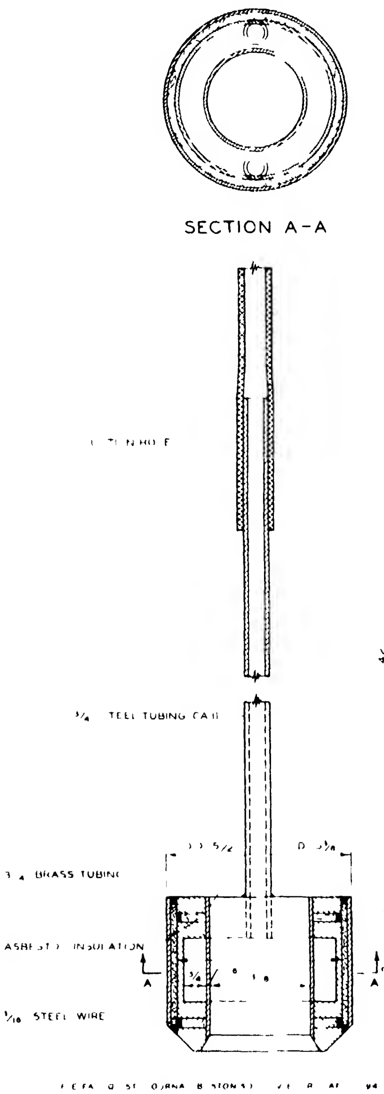
Preparatory operations.- The principal steps in sampling and freezing operations are shown in Fig 247 The bore hole is first cleaned to the edge of the casing by means of a clean-out auger with shielded jet, similar to those shown in Fig 80-82 The sampler and an annular auger, Fig 248, are lowered concurrently so that the annular auger assures proper centering of the sampler in the hole The piston rod is then clamped to the casing or the boring mast, Fig 209 and 210, and the sampler is pushed into the soil in a fast and uniform movement without interruptions or vibrations

The stroke should be slightly smaller than the safe depth of penetration, as determined by previous observations or experiments, in order to avoid creating a void over the sample Even when the safe penetration is not exceeded, the pressure over the sample will be decreased and water will start to flow upward during the drive However, the amount of water which can flow through the sample during the few seconds required for a fast drive is negligible, but if a void is created over the sample by exceeding the safe penetration, the flow of water will continue after completion of the drive and may cause piping and other disturbance of the sample

The clamp between the piston rod and the casing or boring mast should be released immediately after completion of the drive, so that the piston may settle to the top of the sample and prevent further upward flow of water in case the safe penetration should have been exceeded The movement of the released piston rod and the measuring rod, if used, should be determined very carefully and recorded

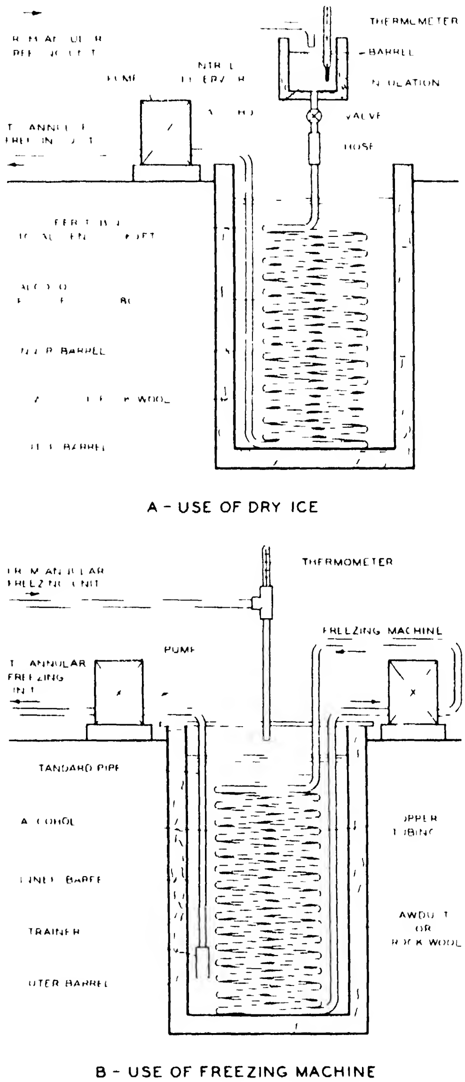
The casing is now advanced and the soil between the sampler and the casing concurrently removed by means of the annular clean-out auger The advance and

cleaning should be terminated a couple of inches above the cutting edge of the sampler, at which depth the distributor ring of the annular auger should rest on the sampler head or on an adjustment sleeve placed on top of the sampler. The cleaning should be performed without imparting shocks or vibrations to the sampler, and the circulation of water should be maintained until the water in the casing is clear Any movements of the piston rod or measuring rod during these operations should be observed and recorded



ANNULAR FREEZING CHAMBER

FIG 249



SURFACE REFRIGERATING EQUIPMENT

FIG 250

The freezing operation.- The clean-out auger is withdrawn and replaced with an annular freezing chamber, Fig 249, which is connected to a refrigerating unit at the ground surface by heavy rubberized hosing The unit originally developed by the **Providence District** consists of coiled copper tubing in an insulated barrel

with ethyl alcohol, Fig 250A, which is cooled approximately to -80°C by means of dry ice The copper tubing, rubber hosing, and annular freezing chamber are also filled with alcohol, which is circulated by means of a small reciprocating pump, normally used in wash boring operations The circulation is maintained for about 15 minutes after the temperature of the return flow has reached -30°C and a 6- to 7-in long section of the sample has been frozen

The refrigerating unit used by the **Waterways Experiment Station** is a standard barrel of 55-gal capacity, insulated and about two-thirds filled with ethyl alcohol However, the copper coil is eliminated, and the cooled alcohol is pumped directly from the barrel through the rubber hosing and the freezing chamber by means of a 1-1/2-in gear pump The intake pipe is provided with a strainer, and thermometers are placed in both intake and return pipes The temperature of the alcohol in the barrel is decreased to about -50°C by addition of dry ice, and the circulation is maintained until the temperature at the intake pipe is about -30°C and/or until the temperature difference between intake and return flow is 4 to 5°C, a condition which usually is attained after 15 to 20 minutes of circulation The elimination of the copper coil simplifies the refrigerating unit and shortens the freezing operation, and cooling the alcohol to -50°C instead of -80°C decreases heat losses and consumption of dry ice and facilitates circulation, since the viscosity of the alcohol is lower at the higher temperatures Excluding losses caused by evaporation during transportation and storage, 75 to 100 lb of dry ice are required per sample when 2 or 3 samples are taken during a normal working day. However, in case of continuous operation and once the refrigerating unit and alcohol has been cooled to -50°C, only 25 lb of dry ice need be added for each sample taken

A freezing machine may be used instead of dry ice, but the required capacity is rather large when the machine is connected directly to the freezing chamber However, it may be possible to reduce the required capacity by using the machine to cool a large quantity of alcohol, Fig. 250B, and then pumping the cooled alcohol through the freezing chamber Experiments have been made with various heat transfer liquids such as methyl alcohol, isoamylalcohol, and trichloroethylene The latter cannot be used where it comes into contact with rubber tubing or packing, and isoamylalcohol deteriorated and curdled after being used for a relatively short period

Any movements of the piston rod or measuring rod during the freezing should be observed and recorded.

Handling of the sample.- When the sampler is operated with released cone clamp, the drill rod should be rotated before withdrawal until the clamp is activated. Great care should be taken to avoid shocks and vibrations during withdrawal of the sampler and freezing chamber. The gross and net lengths of the sample should be determined carefully as soon as the sampler is dismantled. The presence of water between the piston and top of the sample should be noted and it is advisable to measure the quantity, since in some but not all cases it may serve as a check on the

observed changes in length of the sample A temporary seal is now placed in the top of the tube, whereas the bottom is placed in a small container with dry ice in order to maintain the lower part of the sample in frozen condition until the void ratios and water contents of the unfrozen part have been determined Upright position of the sampling tube should be maintained and shocks and vibrations avoided during transportation Vibrations cannot be avoided completely during transportation over long distances, and the samples should therefore be tested in a field laboratory close to the site of the borings

It is difficult to cut a thin-wall sampling tube into short sections and to remove samples of cohesionless soils from the tubing without disturbing the material However, the principal object of undisturbed sampling of cohesionless soils is generally to determine the water contents and void ratios of the sample and the soil in situ This can be accomplished by removing the unfrozen part of the sample in small increments by means of a close fitting cup auger, Fig 345, and determining the volume and weight of each increment, see Section 16 9

After removal of the unfrozen part of the sample, the bottom section of the tubing is exposed to room temperature for a short period or heated lightly, whereupon the frozen bottom section of the sample generally can be pushed out of the tubing as a unit The volume, weight, and water content of the frozen plug is then determined, and it is often sliced longitudinally so that the soil structure can be examined and the dip of the strata determined

Volume changes.- When the sampling is properly performed, the original, total recovery ratio, as determined by movements of the piston rod or the measuring rod during or immediately after the drive, is usually between 98 and 100 percent for a sample with 3-in diameter, 24- to 30-in length, and with 1 percent clearance at the cutting edge of the sampler

When the safe depth of penetration is not exceeded and there are no changes in void ratio, no entrance of excess soil, and no clearance between the sample and the sampling tube, the original recovery ratio should be $(1 - 2C_1)$, where C_1 is the inside clearance ratio, see Section 4 7 However, even when such a recovery ratio is obtained, the soil may have been subjected to a slight compaction, and the corresponding decrease in void ratio and volume may be offset by entrance of a small amount of excess soil A recovery ratio greater than $(1 - 2C_1)$ may indicate entrance of excess soil or actual expansion A recovery ratio smaller than $(1 - 2C_1)$ indicates that actual compaction has taken place and/or that the safe penetration is exceeded with consequent downward deflection, stretching, and reduction in thickness of the soil layers in the lower part of the sample

On account of these various possibilities and more or less compensating changes, the original recovery ratio cannot arbitrarily and safely be used to determine changes in volume and void ratio during the actual sampling Complete specific recovery ratio curves and various observations may permit an estimate of

the volume changes, but systematic experiments and comparative tests are required for accurate determination of such changes. The experiments so far completed indicate that a slight compaction may occur during sampling of loose soils and a slight expansion in sampling of dense soils When the sampling is properly performed and the depth of penetration and the inside clearance ratio so adjusted that the original recovery ratio is between $(1 - 2C_1)$ and unity, the change in volume and density during sampling will usually not exceed 2 to 3 percent and is negligible in some cases.

Changes in length of the sample after completion of the drive, as determined by movements of the piston rod or measuring rod during advance and cleaning of the casing, freezing of the bottom of the sample, and withdrawal of the sampler, indicate definite volume changes, and corresponding corrections should be made When the operations are properly performed, these movements are usually very small or negligible

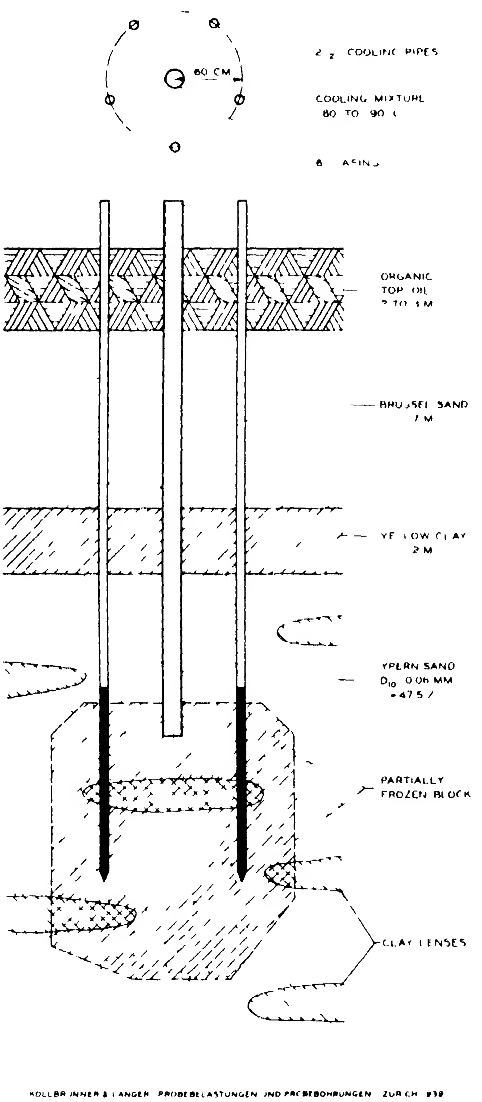
Water will normally expand about 9 percent during freezing, but it is probable that such an expansion during freezing of the lower part of a sample of sand or coarse silt will not cause a material change in void ratio but rather an expulsion of some of the water in the soil Water expelled during the first part of the freezing may escape into the soil below the sampler, but when the freezing is continued after a frozen zone has been formed across the sample, some of the expelled water will flow upward through the sample When the piston has single-acting packing, the water may flow past the piston When the piston has double-acting packing, the water will accumulate on top of the sample and force the piston upward but will not affect the plate connected to a measuring rod Actual upward movement of the top of the sample during the freezing of the bottom of the sample has not been observed so far, and the void ratios of the frozen plug generally agree fairly well with those of the unfrozen part of the sample, whereas the apparent water content and the degree of saturation are smaller on account of the decrease in volume of the water during melting.

11.9 Solidification of the Soil before Sampling

Solidification before sampling of soil adjacent to the bottom of the bore hole is in some cases simpler than solidification of the lower part of the sample and may be required when drive sampling or core boring causes excessive disturbance of the soil in its natural state

Solidification by impregnation with chemicals, grout, asphalt, etc , introduces foreign substances into the soil, and the method cannot be used in undisturbed sampling unless the foreign substances later can be removed from the sample Therefore, cement grout or chemicals which form an insoluble gel are unsuitable for the purpose **J. P. van Bruggen (504) and L. W. Nijboer (131-E)** describe the Shellperm Process by means of which the soil is impregnated with a diluted emulsion of

asphaltic bitumen This emulsion coagulates and imparts thereby considerable cohesion to the soil, and it can be removed by washing with a solution of carbon disulphide and acetone Samples of sand have been obtained by this method, but some difficulties were encountered The impregnation can be accomplished only in fairly permeable materials, and the time required for coagulation of the asphaltic emulsion varies with the character of the soil and the salts dissolved in the pore water It is difficult to force a drive sampler into impregnated sand, but it may be possible to use core boring Considerable time is required for removal of the asphaltic emulsion from the sample, and it is an open question whether the impregnation and subsequent washing with a dissolving agent does not change some of the physical properties of the soil



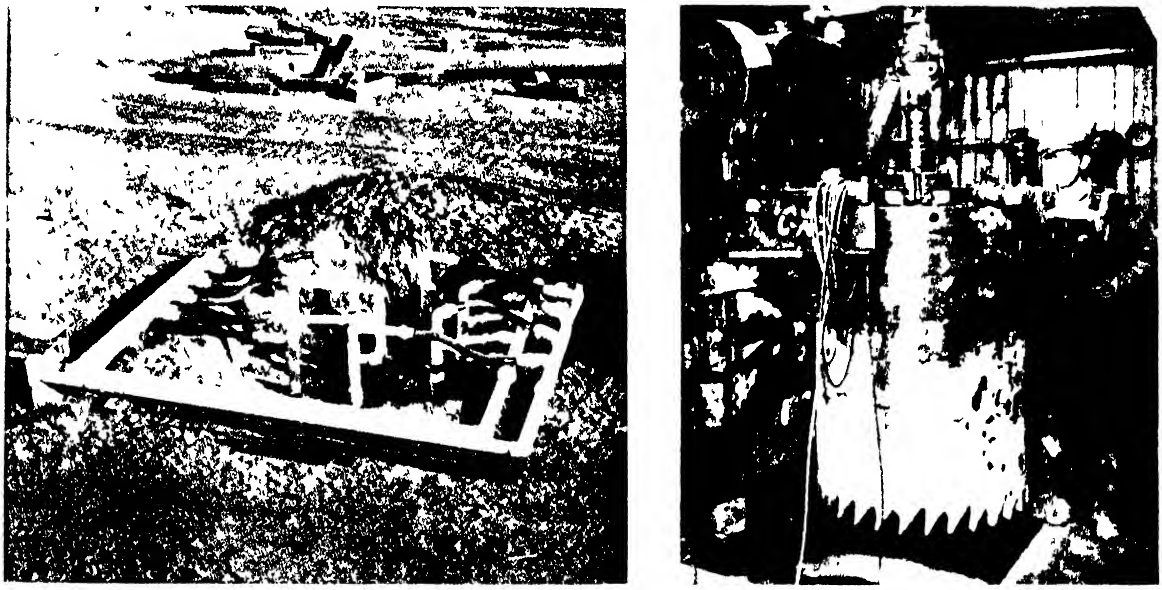
PARTIAL FREEZING BEFORE SAMPLING

FIG 251

Partial or complete freezing of the soil before sampling presents fewer complications than impregnation and has been used in several instances **Langer and Kollbrunner (150, 225, 333)** report successful application of partial freezing or undercooling in sampling of very loose sandy silt Attempts to obtain samples of this soil without freezing were unsuccessful unless one of the scattered clay lenses shown in Fig 251 was encountered at the end of a drive Furthermore, the internal structure of the soil was so unstable that any displacement or vibration produced a considerable decrease in void ratio The cooling was accomplished by driving five 2-1/2-in pipes in a circle around the 6-in boring and partially filling these pipes with a freezing mixture having a temperature of about -80°C The freezing mixture was changed every 2 hours for a total period of about 12 hours The temperature of the soil was thereby decreased and the viscosity of the pore water increased to such an extent that the soil acquired a consistency resembling that of a soft clay The samples could then be obtained without material changes in void ratio and retained in a sampler similar to that shown in Fig. 197. The method can be used only in case of special soil conditions, and preliminary tests are required to determine the optimum length of the freezing period Actual freezing of the soil must be avoided, since the expansion of water during freezing in this

case may cause not only a change in water content but possibly also a change in void ratio and disturbance of the soil structure

Complete freezing of the soil below the bottom of the bore hole was used by the **Corps of Engineers** (110, 911) in sampling operations at Fort Peck Dam Freezing was accomplished by circulating a freezing mixture through seven pipes driven in a circle around the bore hole, Fig 252A, and samples 36 in in diameter were obtained by means of a single tube core barrel with metal teeth and a calyx, Fig 252B The samples were sawed lengthwise into two parts, and excellent photographs were obtained of the soil and rock structure, stratifications, and planes or zones of failure of the material in situ Formation of ice lenses was observed in



A FREEZING OF SOIL COLUMN

B - 36 INCH CALYX CORE BARREL

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FIG 252 - FREEZING OF SOIL COLUMN BEFORE SAMPLING

samples of shale and clayey materials but not in samples of clean sand and gravel This method of sampling is expensive, but it is the only one currently available by means of which relatively undisturbed samples of coarse and gravelly soils can be obtained through bore holes

The **U. S. Bureau of Mines** has performed some experimental boring operations in which the drilling fluid was replaced with kerosene cooled to -30°C The soil around the bore hole was thereby frozen to such an extent that the need of casing through unstable, saturated ground was eliminated. It is possible that this method also can be used in obtaining relatively undisturbed samples of gravelly and broken formations below the ground-water level, and that freezing and core boring can be combined in this manner and the cost of sampling reduced.

11.10 Partial Dewatering by Compressed Air

Samples of cohesionless soils can often be obtained without difficulty when the soil is partially saturated, whereas samples of the same soil in a fully saturated condition are lost during withdrawal. Only a slight decrease in water content may be needed to create a surface tension and apparent cohesion sufficient to prevent

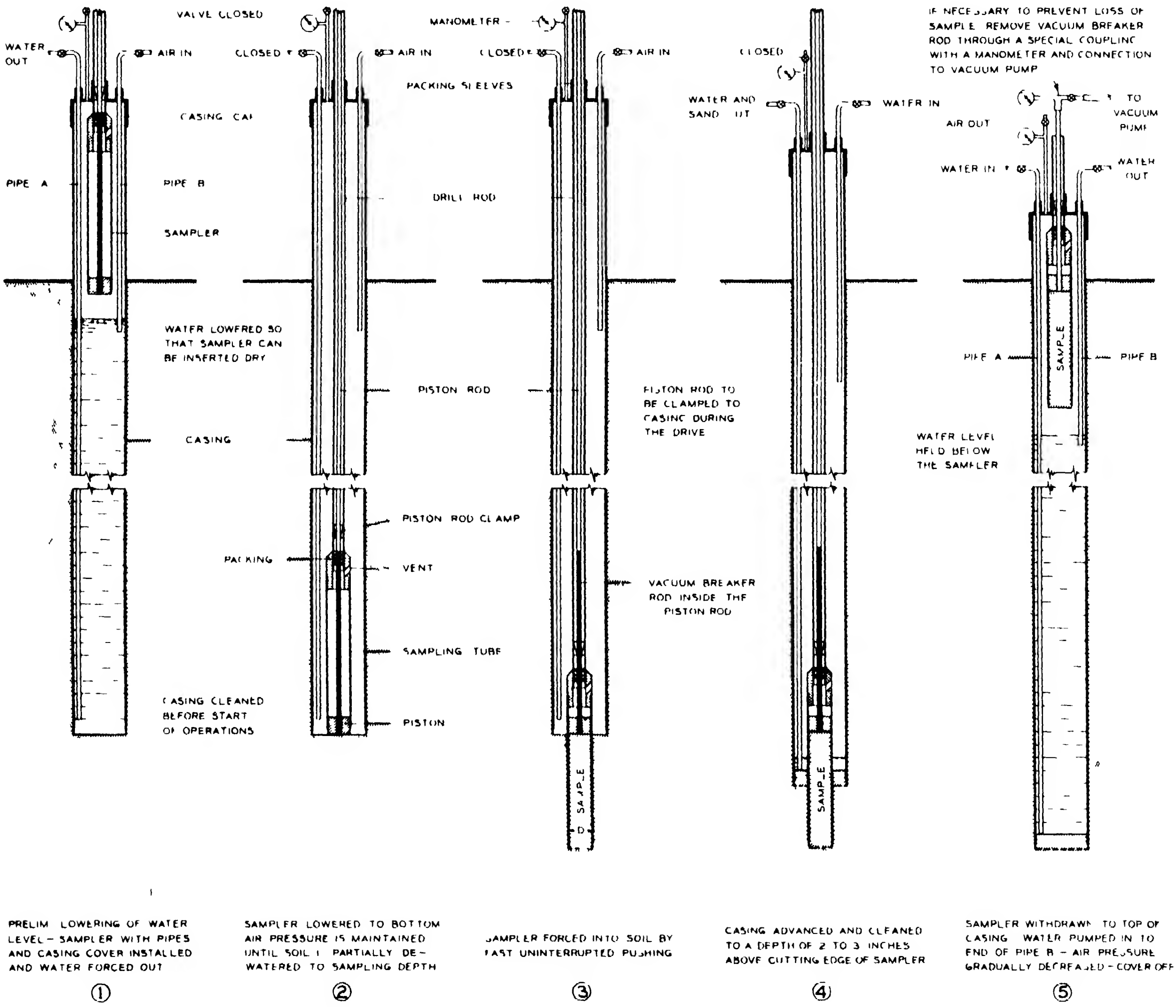


FIG 253 – SAMPLING OF SAND WITH COMPRESSED AIR IN THE BORE HOLE

loss of the sample, as observed by sampling under compressed air in pneumatic caissons and tunnels These commonly known facts and observations prompted **Mr. Milton Vargas,** Chief of Soils and Foundations Division, Instituto do Pesquisas Tecnológicas, São Paulo, Brazil, to suggest to the writer that the loss of saturated, medium- to fine-grained, cohesionless soils might be prevented by operating the boring as a small pneumatic caisson during the actual sampling. Based on this suggestion, the arrangement of equipment and schedule of operations shown in Fig. 253 are tentatively proposed A thin-wall sampler with stationary piston, similar

to those shown in Fig. 205 and 207, is assumed to be used.

The water level in the casing should first be lowered a few feet, so that the sampler can be inserted and the casing cover placed without water entering the space over the piston, where it would remain until expelled when the sampler is driven into the soil The water is now forced out of the casing by means of compressed air, and the sampler can then be lowered to the bottom of the bore hole. Air pressure approximating the total soil pressure at the bottom is maintained for a period sufficient to allow a slight dewatering of the soil adjacent to the bottom of the hole, whereupon the sampler is forced into the soil.

The casing is now advanced and concurrently cleaned out by pumping water and air in through the short pipe, B, and allowing a mixture of soil, water, and air to flow out of the long pipe, A. The advance and cleaning should be stopped a couple of inches from the cutting edge of the sampler. After allowing sufficient time for any remaining water at the bottom of the hole to be forced into the soil below the sampler, the latter is withdrawn to the top of the casing. Water is now pumped in through pipe A and the casing filled to a level slightly below the sampler The water must not reach the sample, since it then would eliminate any capillary tension and apparent cohesion in the soil and might thereby cause loss of the sample. The maximum level of the water can be controlled by means of pipe B

The air pressure in the casing should be decreased gradually to atmospheric pressure as the water level rises The decrease in air pressure below the sample, combined with possible expansion of air in the sample, may cause loss of the sample unless the pressure above it simultaneously is reduced It may therefore be necessary to remove the vacuum breaker rod through a special coupling which also can be attached to a vacuum pump, so that the air pressure over the sample can be maintained at a value slightly less than the air pressure in the casing Care should be taken not to allow this pressure difference to become too great, since a strong upward flow of air through the sample may remove both water and fine soil particles and cause the sample to be unsuitable for accurate laboratory tests When the water in the casing has reached its maximum allowable level and the air pressure is reduced to atmospheric pressure, the cover and the sampler can be removed from the casing.

The sampler should preferably be provided with a cone clamp which can be released during the lowering and driving of the sampler and activated before the withdrawal, so that it will be possible to determine the original length of the sample and any changes in this length during the various operations.

CHAPTER 12
DRIVE SAMPLERS FOR SUBMARINE EXPLORATIONS

12.1 General

Foundation explorations for engineering purposes often have to be carried out through open water in rivers, lakes, bays, and near the ocean shores The methods of exploration and sampling and the equipment described in the foregoing chapters can be used under such conditions without material changes when the distance between the bottom and the water surface is bridged by casing The operations are performed from an anchored float or barge or from a platform supported by piles or by a single pipe of large diameter, Fig 18 and 19

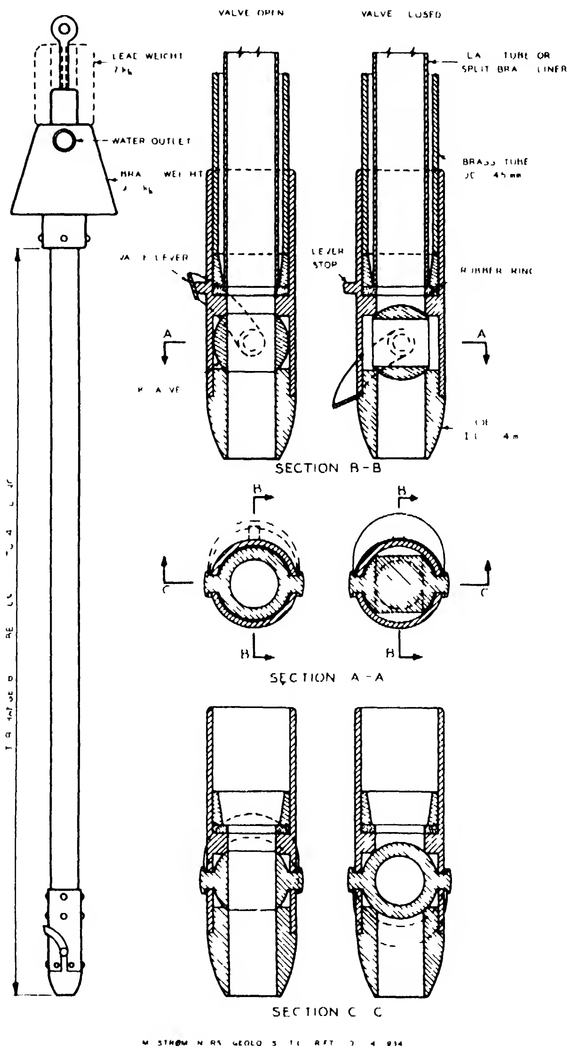
Sampling operations have been performed in the above mentioned manner through open water with depths up to 120 ft, but these methods cannot be used for exploration of the bottom deposits at great depths in lakes and oceans, as required in geological and oceanographic investigations At such depths the sampler must be operated entirely by means of a wire rope. Representative samples of material at the surface of the bottom deposits can be obtained by means of scrapers and buckets whereas drive samplers are used to obtain samples of the deeper strata These drive samplers are generally called coring tubes, and the depth of penetration obtained in a single operation represents the greatest depth to which the bottom deposits can be explored Emphasis is therefore placed on obtaining long samples, and the inside clearance at the cutting edge is often greater than is permissible in undisturbed sampling for engineering purposes. Samples of firm materials up to 10 ft and of soft materials up to 17 ft in length are regularly being obtained by means of open coring tubes At great ocean depths, where enormous hydrostatic pressures are available to force the material into the tube, samples of soft deposits over 60 ft in length have been obtained by means of a recently developed piston coring tube

A very complete review of methods and equipment used up to 1939 in obtaining samples of ocean bottom deposits has been prepared by **Hough (709).** A brief review of the principal and recently developed types of drive samplers for submarine explorations is presented in the following sections. One of these samplers, Fig 259, was used in some of the experiments by the Committee on Sampling and Testing, and some of the others may possibly be used to advantage in preliminary explorations for engineering purposes, when such explorations are to be carried out through open water.

12.2 Standard Gravity Coring Tubes

Most coring tubes used in ocean bottom exploration are forced into the bottom deposits by the gravitational pull on the tube and attached drive weights. Therefore, such samplers are called gravity coring tubes, and the term "Standard Gravity Coring Tube" is used when the tube and weights are attached permanently to the lowering cable so that the velocity of descent is governed or restricted by the unreeling speed of the winch The term "Restricted Gravity Coring Tube" would describe the actual operating conditions more accurately Many standard gravity coring tubes have been developed and differ mainly in the type of liners used and in the arrangement and details of vents, check valves, and core retainers

The coring tube by **Strom (736)** has no check valve and loss of the sample is prevented by a cock valve in the shoe, Fig 254 When the tube is withdrawn, the valve is automatically closed by soil pressure acting on a small external lever This valve has the advantages that in open position it presents a smooth interior surface and that it is nearly watertight in closed position, but it has the disadvantage that it greatly increases the required wall thickness of the shoe and area ratio of the sampler The standard brass weight at the top of the tube has a flat bottom to prevent excessive penetration in soft sediments. Additional weights of lead are placed on top of the brass weight when required by the character of the sediments Samples with a diameter of about 1 in and lengths up to 40 in. are obtained.

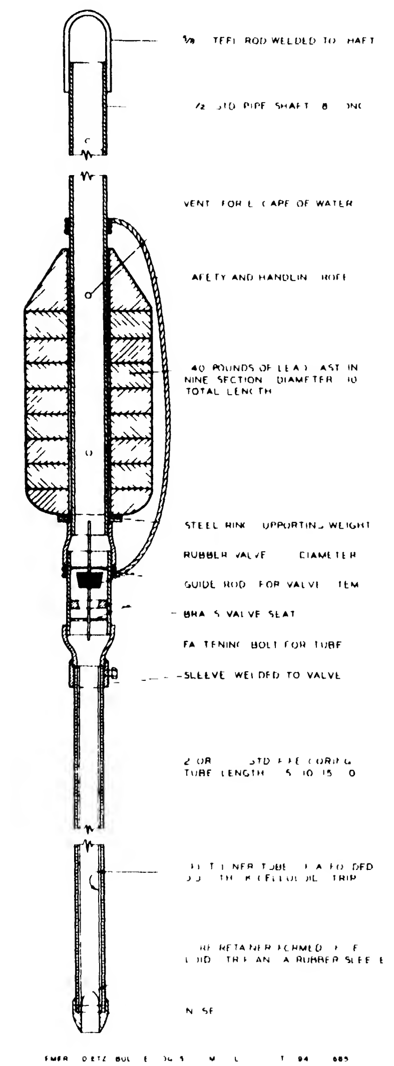


OCEAN BOTTOM SAMPLER BY STRØM

FIG 254

A coring tube designed by **Emery and Dietz (705)** for the Scripps Institution of Oceanography is shown in Fig 255. It is composed of standard pipe and fittings and has a liner with a single open seam, formed of a strip of thin celluloid. After

withdrawal and dismantling of the sampler, the celluloid liner is easily opened for inspection of the sample, which is cut into short sections and preserved in glass containers Loss of the sample is prevented by a rubber check valve and a core retainer made of celluloid strips and a rubber sleeve, Fig 233F The low coefficient of friction of soil on celluloid and the use of cutting edge with inside clearance ratios of 8 to 16 percent reduce the inside friction to such an extent that cores up to 17 ft in length have been obtained of soft diatomaceous mud and up to 15 ft in silty and clayey mud The average length of cores of these materials is about 13 ft, whereas cores of sand and firm clay are less than 42 in long The total recovery ratio usually varies between 41 and 68 percent, and these low values can in part be attributed to the influence of the very large inside clearance and consequent slumping of the material after it enters the tube



EMERY-DIETZ GRAVITY CORING TUBE

FIG 255

12.3 Free-Fall Gravity Coring Tube

The energy available to force a gravity coring tube into the bottom sediments is composed of the static energy or weight of the tube and attached drive weights, and of the kinetic energy or velocity of the assembly as the tube reaches the bottom The weight of the tube and drive weights is limited by the capacity of the winch, the strength and weight of the cable, and the additional force required to pull the tube out of the bottom sediments The safe unreeling speed of a winch and therefore the downward velocity of a standard gravity coring tube is normally between 3 and 10 ft/sec, and this velocity does not increase the total available energy appreciably **Emery and Dietz (705)** increased the downward velocity to about 20 ft/sec by allowing the winch to run on the brake for the last part of the descent This method cannot always be used with safety, and a velocity of 20 ft/sec is not always sufficient to cause full penetration of the coring tube into stiff materials Additional velocity and energy can be obtained by attaching the coring tube with drive weights to the cable in such a manner that it is released at a predetermined distance from the bottom and then allowed to fall freely through the water

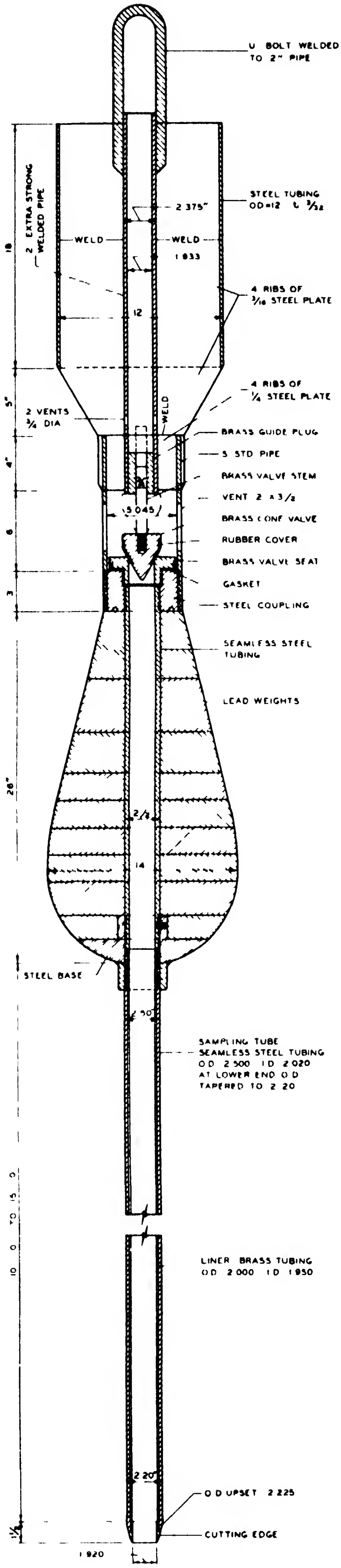
The principal steps in the operation of such a free-fall coring tube, developed

for the Woods Hole Oceanographic Institution by **Hvorslev and Stetson (710)** and built in 1940, is shown in Fig 256 The coring tube with a streamlined drive weight and guide vanes, Fig. 257, is permanently attached to the base plate of a release mechanism, Fig 258, by a chain called the withdrawal chain During lowering to the ocean bottom, this chain is bunched-up and secured with twine to the drive weight. The latter is suspended from the short arm of the lever in the release mechanism and is balanced by a small pilot weight and light chain attached to the long arm of the lever The length of the pilot weight chain is so adjusted that the distance from the weight to the cutting edge of the coring tube is equal to the desired height of the free fall plus the upward movement of the lever required to release the drive weight

When the pilot weight strikes the bottom, the balancing force on the lever is eliminated, and the drive weight and coring tube are released and fall freely through the water, breaking the twine and straightening the bunched-up withdrawal chain The sudden release of the drive weight and coring tube and corresponding relaxation of tension in the cable causes a wave to travel up the cable and to be clearly registered by a dynamometer The winch is immediately stopped, and the entire assembly is withdrawn after allowing sufficient time for completion of the free fall and penetration of the coring tube In contrast to the clear indication of release of a free-fall coring tube, the tension in a cable to a standard gravity coring tube is decreased gradually as the tube penetrates the bottom sediments, and it is often difficult to determine when the coring is completed It is then necessary to pay out excess cable, which may form coils on the ocean bottom and then tangle and kink when taken in

The velocities attained depend not only on the height of the free fall, but also on the resistance exerted by the water and therefore on the shape and coefficient of drag of the drive weight and coring tube This resistance increases approximately with the square of the velocity, with increasing height of fall it will ultimately become equal to the submerged weight of the falling body, and the maximum possible or terminal velocity is then reached The coefficient of drag for the coring tube shown in Fig 257 has not been determined, but probable upper and lower limits were estimated and the corresponding terminal velocities found to be between 60 and 90 ft/sec The drag has relatively little influence on the velocities attained when the drive weight is streamlined and the free fall is less than 30 to 40 ft Even when the coring tube is released just above the bottom, the velocity will increase until the sum of the drag and the penetration resistance equals the submerged weight of the tube and its drive weight, and the energy available to force the tube into the sediment is nearly twice as great as for a comparable standard gravity coring tube In case of the latter, the active downward force is not equal to the submerged weight of the tube and drive weight, but only to the difference between this weight and the tension in the cable, and the gradual relaxation of the tension with increasing penetration consumes about 50 percent of the available static energy

So far, only small free falls have been used, generally less than 15 ft above



DETAILS OF FREE FALL CORING TUBE

FIG 257

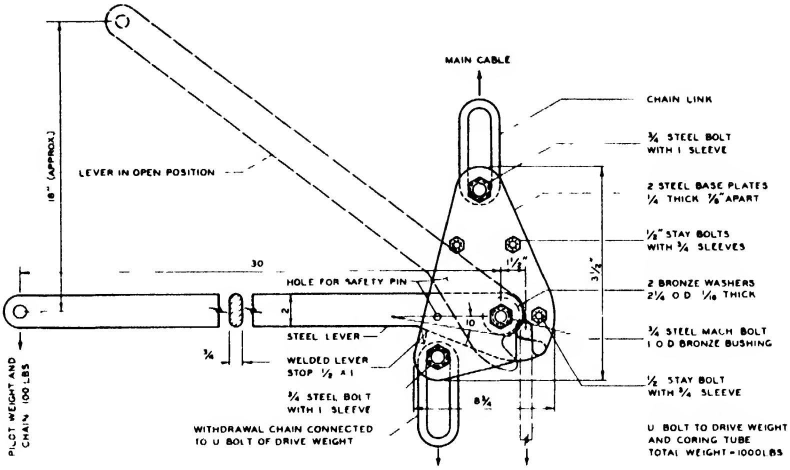
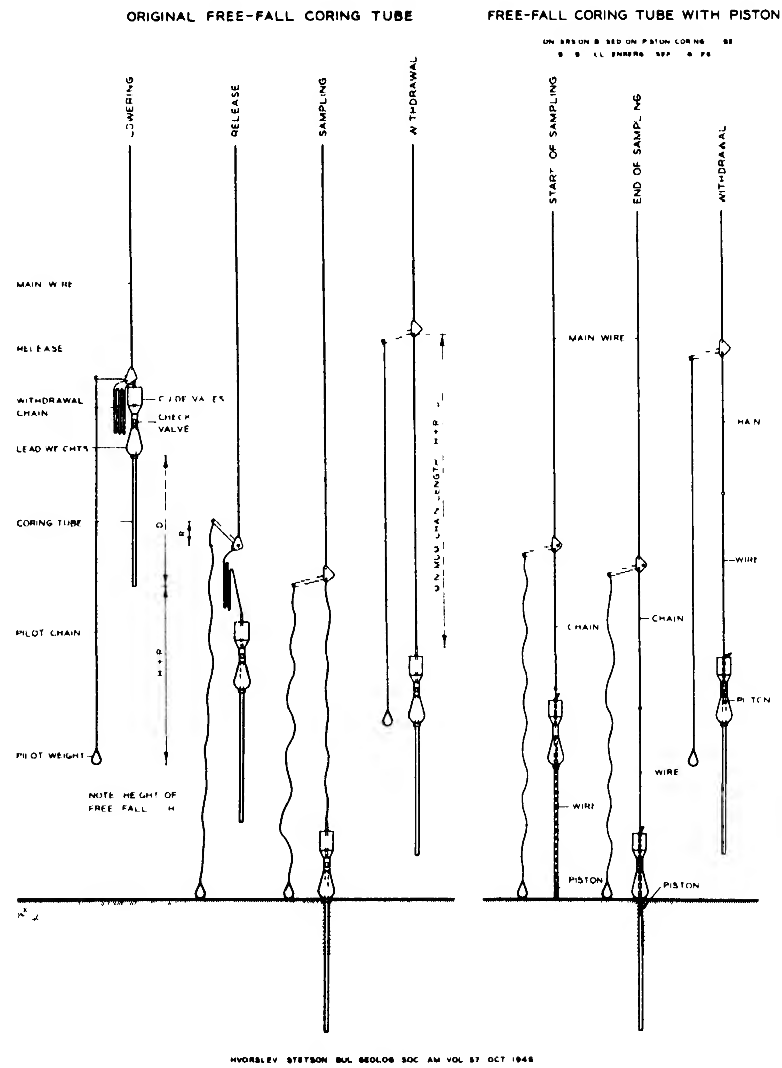


FIG 258 - DETAILS OF RELEASE MECHANISM



OPERATION OF FREE-FALL CORING TUBE

FIG 256

the ocean bottom. However, the energy developed has been sufficient, except in very stiff and silty clay, to force a 10- to 15-ft long tube and a part of the drive weight into the sediments Much greater velocities can be attained and more energy made available by increasing the height of the free fall Therefore, it is possible to reduce the size of the drive weight or, conversely, to increase the length or diameter of the coring tube With 1 percent inside clearance at the cutting edge, cores up to 10 ft in length have been obtained of medium stiff clay with strata of sand and gravel and pebbles up to 1-1/2 in in diameter Much longer cores can undoubtedly be obtained by using shoes with a larger inside clearance, but the danger of losing the core will then be increased, and a core catcher may be required

This free-fall coring tube has been used successfully through more than 13,000 ft of water, and there is no reason to doubt that it can be used at much greater depths The stratifications in all the cores obtained are practically horizontal, indicating that the guide vanes hold the tube in vertical position during the free fall Theoretically, there is danger that the assembly may rotate during lowering, wrap the pilot weight chain around the coring tube, and thereby prevent proper release of the tube or cause it to hit the pilot weight Difficulties of this kind have not yet been encountered; nor did the roll of the ship ever cause premature release of the coring tube An accidental release occurred once when a clutch failed and the unreeling speed became so great that the winch had to be brought up short on the brake The 2000 ft of cable paid out at that time cushioned the fall, and only a heavy jar was felt at the ship

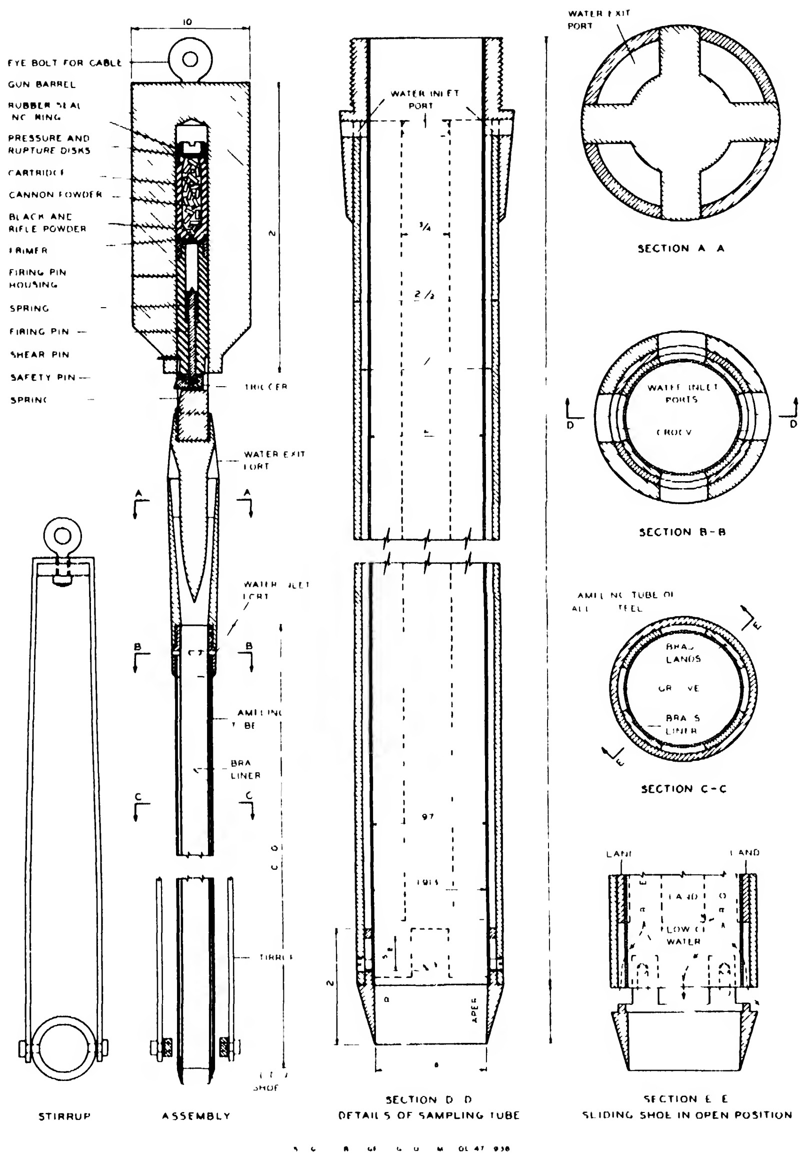
The diagram on the right-hand side of Fig 256 shows a free-fall coring tube with a piston attached to the withdrawal chain The piston remains more or less stationary while the tube penetrates the bottom sediments, and much longer cores can then be obtained This principle of operation was developed by **Kullenberg** and is discussed further in Section 12 5 The right-hand diagram in Fig 256 was drawn before the details of the piston coring tube were published, and it is retained since it helps to explain the principles of the method

12.4 Coring Tube Driven by Explosives

An ingenious method of supplying sufficient energy to drive a long coring tube into stiff submarine deposits was developed by **Piggot (725, 726)** in 1935 The method consists in utilizing the usual drive weight as a gun barrel and the coring tube as the projectile, Fig 259.

The tube is connected to an adapter with water exit ports, and the adapter is in turn attached to a cylinder containing a trigger mechanism and a cartridge with gunpowder During lowering of the entire assembly through the water, the weight of the coring tube, adapter and cartridge cylinder is carried by two small shear pins through the lower part of the gun barrel A retrieving stirrup is suspended from the top of the gun barrel by means of a wire rope of such length that the ring of the stirrup is slightly above the cutting edge of the coring tube. When

the tube meets resistance at the bottom, the gun barrel slides down over the trigger and fires the cartridge. The coring tube is thereby forced down at great velocity, breaking the shear pins and passing through the ring of the retrieving stirrup and into the bottom sediments. The ring cannot pass over the adapter, and the tube can therefore be recovered by means of the stirrup and the wire rope to the top of the gun barrel and main cable.



PIGGOT CORING TUBE DRIVEN BY GUNPOWDER

FIG 259

The channels leading to the water exit ports are streamlined, and the total area of the ports is slightly larger than that of the coring tube, the consequent Venturi effect decreases the excess hydrostatic pressure over the core as it enters and forces water out of the tube. The brass liner is separated from the outer barrel by four lands, and water can flow from the top to the bottom of the barrel through the channels thus formed. The danger of clogging of the outlets for these channels is decreased by use of a sliding shoe. A flow of water through these channels helps to maintain but cannot entirely prevent a decrease in hydrostatic pressure below the coring tube during the withdrawal and until the cutting edge is above the bottom sediments.

The Piggot coring tube has been used successfully in ocean bottom explorations through more than 20,000 ft of water. Many 10-ft long cores have been obtained, and they show relatively little distortion of the soil layers in spite of the fact that experiments by **Piggot (727)** and by the **Committee on Sampling and Testing,** see

P-7 in Fig. 108A, indicate that the specific recovery ratios generally decrease fairly uniformly from the top to the bottom of the core However, most of these experiments, as well as practical coring operations, were performed with coring tubes having shoes without inside clearance at the cutting edge As shown in Fig 100, better recovery ratios and longer cores are obtained when adequate inside clearance is provided

12.5 Vacuum and Piston Coring Tubes

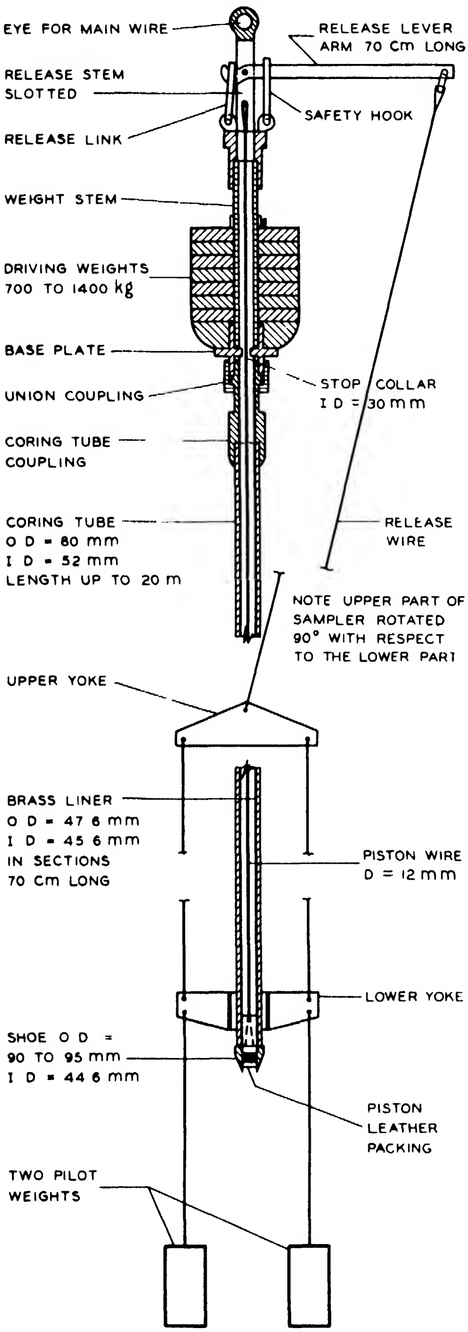
The hydrostatic pressures at great ocean depths represent enormous forces which may be used to drive the coring tube into the bottom sediments and/or to force the material into the coring tube

Vacuum drive cylinder.- An attempt to utilize the hydrostatic pressures to drive a coring tube into the bottom deposits was made by **Varney and Redwine (742, 743),** who connected the coring tube to a piston in an evacuated cylinder When the bottom is reached, a large valve is automatically opened and water admitted to the top of the evacuated cylinder The hydrostatic pressure then forces the piston and coring tube down, whereas the recoil of the drive cylinder is decreased to a small amount by resistance to rapid upward movement of a large circular plate attached to the cylinder As far as is known, the method has not been developed beyond the experimental stage

Vacuum coring tubes.- Extensive experiments have been made by **Petterson and Kullenberg (723, 724)** in an effort to utilize the hydrostatic pressures to force the bottom sediments into a coring tube by attaching the tube directly to an evacuated cylinder or sphere A regulating valve with a piston temporarily closes the opening between the tube and the sphere, and the entire assembly is operated as a standard gravity coring tube The piston is released by a valve rod or pilot weight when the coring tube strikes the bottom, and water from the tube then flows into the sphere and is replaced with soil from the bottom deposit The opening in the regulating valve or plate is so adjusted according to depth and hydrostatic pressure that the rate of flow into the sphere corresponds to the average rate of penetration of the coring tube Furthermore, the sphere is partially filled with water so that the remaining void has the same volume as the core for a desired depth of penetration and 100 percent recovery, and entrance of excess soil after completion of the penetration is thereby avoided

The total friction and adhesion between the core and the coring tube increases and the hydrostatic pressure over the core and the rate of flow through the regulating valve decrease with increasing penetration Since the assembly is operated as a standard gravity coring tube, the rate of penetration is equal to the lowering speed and is, therefore, fairly constant until the submerged weight of the coring tube and the sphere equal the penetration resistance, whereupon the speed of penetration rapidly decreases to zero When the setting of the regulating valve is not changed

during the penetration, too much soil will enter the tube during one part and too little during another part of the penetration It is also difficult to predetermine the depth of penetration and the required volume of the void in the sphere On account of these uncertainties and various mechanical difficulties when operating at great depth below the water surface, the vacuum coring tube was discarded in favor of a piston coring tube developed by **Kullenberg (715, 716, 717)** and shown in diagrammatic form in Fig 260



B KULLENBERG THE PISTON CORE SAMPLER
SVENSKA HYDROGRAFISK – BIOLOGISKA KOMMISSIONENS SKRIFTER
TREDJE SERIEN BAND I – HAFTE 2 – GÖTEBORG, 1947

PISTON CORING TUBE
FIG 260

Piston coring tube -- principle.- The Kullenberg piston coring tube is a gravity coring tube with limited free fall and the lower end closed with a piston until actual coring is started The piston is connected to the main cable by a wire rope of such length that it is stretched out and taut at the moment the coring tube strikes the bottom, see Fig 256 The piston will then be held more or less stationary, subject only to the movements of the lower end of the main cable, while the coring tube slides past the piston and into the bottom sediment The pressure below the piston and over the core decreases with increasing penetration and increasing friction and adhesion between the core and the tube The difference between the hydrostatic pressure in the sediment and the pressure over the core tends to compensate for the resistance exerted by the inside friction and adhesion and helps to force material into the tube, so that much longer cores can be obtained than with an open coring tube The upward movement of the piston with respect to the coring tube is limited by a stop collar or inside shoulder, so that the coring tube and drive weight can be withdrawn by means of the piston rope or chain

Structural details.- The coring tube proper, Fig 260, consists of an outer steel tube and a sectionalized brass liner The outer tube, which may be 20 m or more in length, is divided into 5-m long sections with screw joints The brass liner is drawn to very accurate dimensions, and the 70-cm long sections are joined by means of tight

fitting slip rings. Loss of cores of very soft materials is prevented by means of a core retainer which consists of a single cylindrical segment or inverted clam shell and can be released by a small downward movement of the sliding shoe The outside diameter of the shoe is increased to assure that the soil pressure against the shoe or resistance to withdrawal is sufficient to produce a downward movement of the shoe and thereby release the core retainer As a consequence, the area ratio is extremely large, about 350 percent

The outer tube is joined to the base plate and weight stem by a union coupling which facilitates assembling and dismantling the tube The lower drive weight is semispherical in shape, additional weights in the form of slotted iron disks can be added as required by the desired depth of penetration and the consistency of the bottom deposit The maximum total weight is about 1500 kg The base plate has an interior shoulder or rib which restricts the vent diameter to 30 mm and serves as a stop collar for the piston The latter has leather packing and is connected to the slotted release stem by a wire rope The release stem and lever are permanently attached to the main cable and connected to the weight stem by a sliding joint Through a link on top of the weight stem, the drive weights and coring tube are suspended from the short arm of the release lever and balanced by two pilot weights, suspended from the long arm of the lever and kept in symmetrical position with respect to the coring tube by means of a sliding yoke

Operation.- During lowering to the ocean bottom, the pilot weights are suspended about 1 m below the cutting edge of the coring tube When the pilot weights come to rest on the bottom, the balancing force on the lever is removed, and the drive weight and coring tube are released and fall freely, whereas the piston is held more or less stationary by the wire rope to the release stem The lowering speed, when approaching the bottom, is so adjusted that it will compensate for the velocity with which the lower end of the main cable tends to move upward upon release of tension in the cable, see paragraph on immobilization of piston The total weight of the coring tube and drive weights should preferably be so adjusted that the piston barely touches the stop collar when the maximum penetration is attained When the drive weight is too heavy, the piston may be brought up against the stop collar with considerable force, and when the weight is too light, the piston will be below the collar at the end of the penetration, and it will be pulled up to this collar at the start of the withdrawal The consequent reduction of pressure below the piston may cause entrance of excess soil or collapse of the liner, unless the withdrawal is so slow that leakage through the joints will keep the pressure reduction within tolerable limits.

In the absence of guide vanes, the drive weight and coring tube are kept in upright position during the free fall by a taut piston rope This arrangement limits the free fall above the ocean bottom to a small distance, whereas that shown in Fig 256 permits any desired height of the free fall However, even when the free fall above the bottom is zero, the release from the main cable will cause the available

static energy to be nearly twice as great as that of a comparable standard gravity coring tube

Immobilization of the piston.- Attachment of the piston to the release stem and main cable is a very simple and practical arrangement, but the question arises whether it will hold the piston in a sufficiently stationary position during the actual coring operation **Kullenberg** (717) presents a detailed analysis of this problem. When the drive weight and coring tube are released, a relaxation wave will travel up the main cable with the speed of sound in steel, about 5000 m/sec, and will impart to the lower end of the cable and the piston a relative upward velocity which depends on the diameter and length of, and the original tension in the cable When the lowering velocity is made equal to the upward velocity induced by the release, the piston will be immobilized temporarily The relaxation wave is reflected at the winch, and when the reflected wave reaches the lower end of the cable, the piston starts to travel downward When the depth of water is great, over 15,000 to 20,000 ft, the penetration of the coring tube will be completed before the reflected wave reaches the piston Moreover and independent of depth, if the winch is stopped at exactly the right moment upon being reached by the first relaxation wave, further waves in and movements of the main cable will theoretically end

The above considerations must be modified to take into account other forces acting on the cable and piston **Kullenberg** suggests that the effect of drag on the cable and of excess hydrostatic pressure over the piston -- produced by forcing water out through the restricted opening formed by the stop collar -- may be compensated for by a suitable reduction of the effective weight acting on or the tension in the cable, used in computing the lowering velocity which will compensate the induced upward velocity upon release of the coring tube However, the excess hydrostatic pressure over the piston varies with the square of the velocity of penetration of the tube Moreover and on account of the extremely large area ratio, excess soil may tend to enter the tube and cause an upward force on the piston during the first part of the penetration, but the total inside friction increases and the pressure on the bottom of the piston decreases with increasing penetration until the safe depth of penetration is reached and a partial vacuum is formed below the piston The resultant force on the piston therefore varies between wide limits during the penetration Rolling and pitching of the ship during actual coring may cause movements of the piston when the depth is small and the cable short, but the influence of surface movements decreases with increasing length of the cable and is probably negligible at great depths

It is problematical that these various forces and movements can be fully counteracted, and that the currently used arrangement in attaching the piston to the main cable will hold the piston completely stationary during the actual coring. Movements of the piston and consequent entrance of too much or too little soil, combined with the influence of the extremely large area ratio, may cause partial disturbance of the core or certain sections thereof

Results and comments.- The length of core obtainable depends on the consistency of the bottom sediments and on the depth below the water surface or hydrostatic pressure which helps to force the material into the tube. The paper by **Kullenberg (717)** contains a photograph of a 45-ft long core obtained at a depth of 8000 ft. The upper part of this core shows slight convex distortions which may have been caused by the inside wall friction or by entrance of excess soil. The lowest part of the core shows concave distortions which indicate that the safe penetration has been reached and that the soil layers are being deflected downward, stretched, and reduced in thickness before entering the coring tube. It is reported that several 20-m long cores of soft sediments at great depths have been obtained in later operations.

Although a possible disturbance of the core, as discussed above, may be objectionable in subsurface explorations for civil engineering purposes, it may be of only minor importance in oceanographic explorations. As mentioned in Section 12.1, the penetration of the coring tube represents the maximum depth to which ocean bottom sediments can be explored. The Kullenberg piston coring tube has more than trebled the depths formerly attained, and it represents a major advance in ocean bottom exploration.

CHAPTER 13
CORE BORING METHODS AND EQUIPMENT

13.1 General

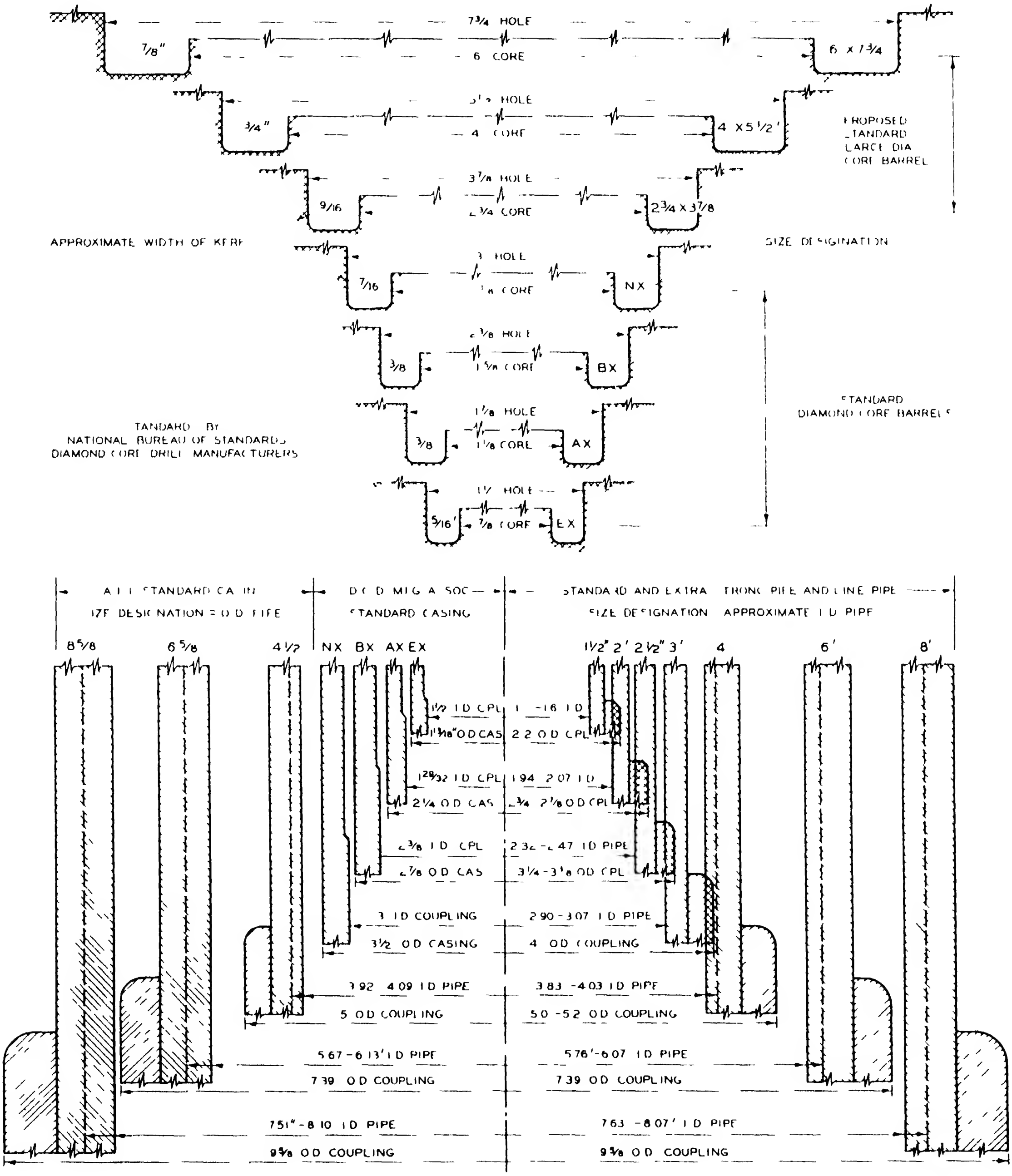
Reference is made to Sections 4 16 to 4 19 for a discussion of the general principles of core boring, types of core barrels, and drilling machines used in operating the barrels This chapter contains a more detailed description of rotary core barrels commonly used in subsurface explorations for civil engineering purposes Some of these core barrels are also used in explorations for other purposes, in actual construction, mining, quarrying, etc Details of other methods of boring and sampling, used in explorations for oil and minerals, are described in Chapter 14.

Core barrels are built in a great variety of types and sizes The principal dimensions of the smaller core barrels, primarily with diamond coring bits, and appurtenant equipment have been standardized for nearly 20 years At a meeting of the American Institute of Mining and Metallurgical Engineers in March 1947, tentative standards were proposed for core barrels over 2 in and less than 10 in in diameter and of the type shown in Fig 271, **Schank (547).** The diameters of the holes bored and the cores obtained by core barrels included in these adopted and proposed standards are shown in diagrammatic form in Fig 261 together with the corresponding diameters of various types of pipe used as casing Further details of such pipe are given in Chapter 8

13.2 Single Tube Core Barrels with Metal Teeth

Core barrels having bits with teeth or cutters of steel or hard-metal alloys are primarily used in stiff, dense, or partially cemented soils, and in soft or broken rock The simplest of such core barrels is the "poorboy", Fig 262, so called because it is made of any available pipe with suitable diameter and wall thickness and because it is used when regular core barrels are not available or too expensive to procure for a particular purpose. Teeth are cut in the lower end of the pipe by means of a hacksaw or blowtorch, and a plate and drill rod coupling are welded to the upper end of the pipe The teeth are given a set to produce a cut with sufficient clearance for passage of wash water or drilling fluid. Long teeth and relatively thin pipe are used when cores of sticky or clogging materials are to be obtained. When the cores are difficult to retain by "burning-in" or "dry-blocking", heavy pressure is applied to the drill rod before the withdrawal, and the long teeth are then bent inward and form a basket under the core. After withdrawal the pipe is

cut above the teeth, the top of the barrel is connected to the pump, and the core is pushed out of the barrel by hydrostatic pressure New teeth are cut in the remaining part of the core barrel, if it is long enough, or the top plate and coupling



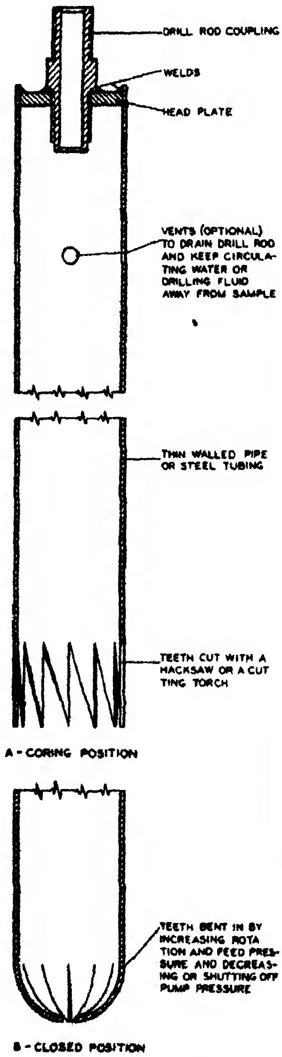
BASED ON DIAGRAM BY E J LONGYEAR CO - MINOR CHANGES

FIG 261 - NOMINAL SIZES OF STANDARD CORING BITS CASING AND PIPE

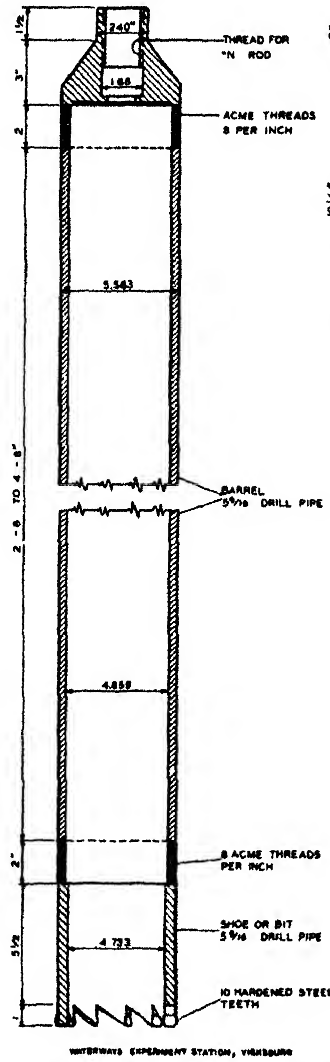
are cut out and welded to a new barrel

Vent holes are occasionally drilled in the upper part of the barrel or the lower part of the drill rod in order to permit drainage of the drill rod during

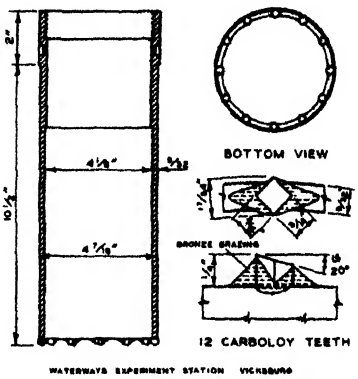
withdrawal, to avoid a disagreeable "wet pull", and to prevent formation of excess hydrostatic pressures in the upper part of the barrel and consequent danger of loss of the core. However, such vents divert a part of the circulating water or drilling fluid, and vents in the core barrel proper also prevent use of hydrostatic pressure in forcing the core out of the barrel.



"POOR BOY" CORE BARREL
FIG. 262

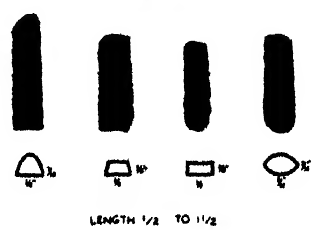


VICKSBURG SINGLE TUBE CORE BARREL
FIG 263



ASPHALT CORING BIT
FIG 264

CALYX TEETH
FIG 265-A



HARD METAL INSERTS
FIG. 265-B

Although the "poorboy" must be considered as makeshift equipment, the same principles of construction are regularly used in single tube core barrels of large diameter, Fig. 252B, but the teeth are then carefully machined and surfaced with hard-metal alloys. Single tube core barrels of small and medium size are generally provided with a removable core barrel head and often with a replaceable coring bit. The teeth may be machined in the bit, Fig. 263, or may consist of hardened steel inserts, Fig. 265A, which can be replaced when dull. In recent years

steel teeth are nearly always surfaced with hard-metal alloys, consisting mainly of tungsten carbide with small amounts of borium, chromium, cobalt, or manganese and sold under various trade names, such as Haystellite, Borium, Stoodite, Carboloy, etc These alloys are furnished as small particles embedded in a rod or sheath of steel and are applied to the bit by acetylene or electric welding

Still greater hardness and wearing resistance can be obtained by using inserts of either cast or fused tungsten carbide alloys These inserts are available in a large number of shapes and sizes, some of which are shown in Fig 265B The inserts may be used to provide cutting edges on machines or forged teeth, but they are more often placed in holes or grooves in a plain bit and serve directly as cutters They are fastened to the bit by peening or welding Not only the shape and size but also the arrangement of the inserts varies with the size and type of bit and with the character of the material in which the bit is to be used An example of a single tube with a bit consisting of Carboloy inserts is shown in Fig 264 Although this core barrel primarily is designed for obtaining cores of asphalt concrete, the bit setting can also be used for coring of subsurface materials of comparable hardness

Single tube core barrels are simple in construction and operation, the kerf area is smaller, the diameter of the core larger, and the rate of progress generally greater than for a double tube core barrel of equal outside diameter Satisfactory cores of firm, sound, and uniform rock can be obtained with single tube core barrels of both large and small diameter On the other hand, cores of soils and soft or broken rock obtained with single tube core barrels of small to medium diameter are generally seriously disturbed by swelling or slaking on contact with free water, failure of the material in torsion, and by erosion of broken-up and weak materials In many cases the major part of cores of weak materials is broken up and removed by the circulating water or drilling fluid

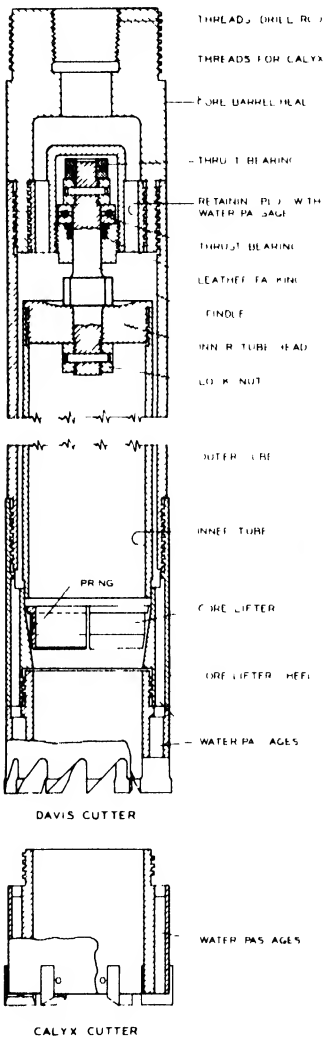
To avoid changes in water content and erosion of weak materials, single tube core barrels are occasionally operated in dry bore holes, without circulation of water or drilling fluid, and forced into the material under high feed pressure and rapid rotation Representative samples of stiff clays or soft shales with intermittent seams of silt and sand can be obtained in this manner, but the material will generally be subjected to serious structural disturbance

13.3 Double Tube Core Barrels with Metal Teeth

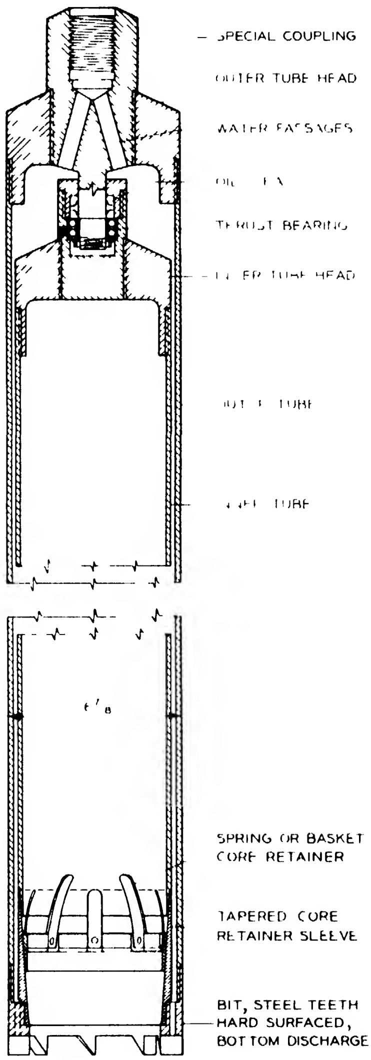
Double tube core barrels with metal teeth are commonly used in obtaining cores up to 10 in in diameter of very stiff and brittle, dense, or partially cemented soils and of soft, broken, fissured, and friable rocks To obtain maximum protection of the core against torsional forces and erosion by circulating water or drilling fluid, most of these core barrels have an inner tube with swivel head and a bottom discharge bit The bit may have hard-surfaced steel teeth or hard-metal inserts, and the comments on these cutting media made in the foregoing section also apply

to double tube core barrels and bottom discharge bits In case of coring through alternating hard and soft strata and when the diameter of the core barrel is small, the hard-metal inserts are often replaced with diamonds or with inserts containing diamonds

Retracted inner tube.- In double tube core barrels, used in partially cemented soils and soft rock, the inner tube extends only to the core retainer or the coring bit proper In the core barrel shown in Fig 266, manufactured by the **Ingersoll-Rand Co. (139)**, the core catcher unit is attached to and rotates with the coring bit, whereas the core catcher unit in the core barrel shown in Fig 267, manufactured by the **George E. Failing Supply Co. (121, 122)**, is attached to the inner tube and does not rotate during coring In the latter case the section of the core which is exposed to direct transmission of torsional forces from the rotating bit is very small, and the danger of disturbance is decreased However, in either case, friction between the bit and the core is theoretically eliminated by a bit setting which cuts the core with a diameter slightly smaller than that of the inner tube, and by omission of vents in the inner tube so that fluid over the core must be forced out between the core and the inner tube



DOUBLE TUBE CORE BARREL
FIG 266



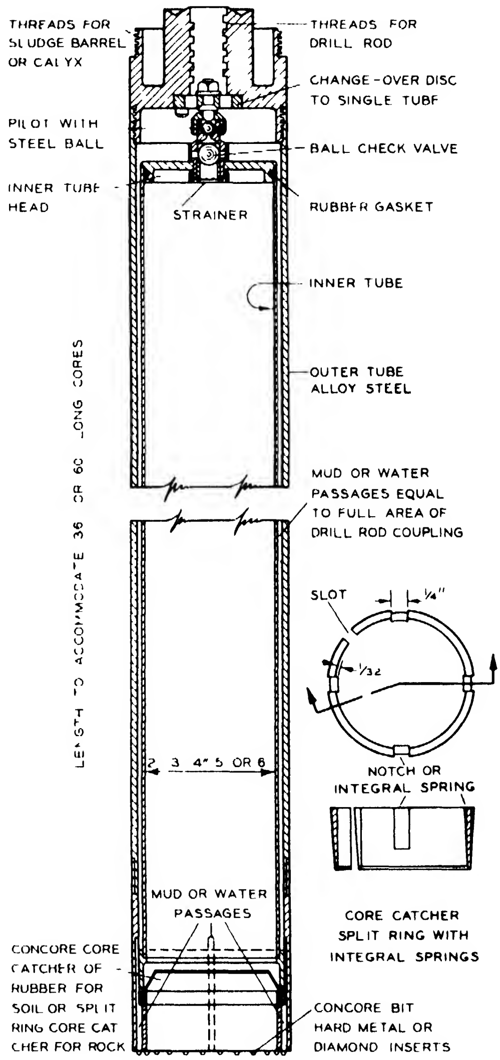
GEO E FAILING SUPPLY CO ENID OKLAHOMA

FAILING DOUBLE TUBE CORE BARREL
FIG 267

Omission of vents in the inner tube has the advantages that it simplifies construction and that it definitely prevents formation of excess hydrostatic pressures over the core during withdrawal, whereas a check valve may be rendered ineffective by dirt and permit leakage of fluid from the drill rod to the inner tube On the other hand, contact between the fluid and cylindrical surface of cores of soil and soft rock

may cause swelling, slaking, or slumping of the core If the clearance between the core and the tube is eliminated for this or other reasons, very large hydrostatic pressures will be created in the inner tube during the coring and hinder entrance of material When the clearance between the core and the tube is maintained, the inside wall friction is negligible, and the core retainer alone must resist all the forces which tend to cause loss of the core The Ingersoll-Rand core barrel, Fig 266, has a split ring core catcher which is most effective when the core consists of sound and firm rock but often fails to retain cores of soils and soft or broken rock The Failing core barrel, Fig. 267, is provided with a combination split ring and spring type core catcher and therefore is better able to retain cores of both soft and firm materials, however, the stiff springs shown in the figure may cause disturbance of and hinder entrance of soft materials

The Concore double tube core barrel, manufactured by the **Frank L. Howard Engineering Co.** (127, 128), has an inner tube which is provided with a small inside vent and is centered by a cap and thrust pilot instead of being suspended from a spindle, Fig 268 During the lowering and seating of the core barrel, the inner tube and attached core catcher unit rest on the coring bit but are forced up against the thrust cap when the friction between the core and the inner tube exceeds the submerged weight of the latter The inner tube extension with the core catcher unit is guided by making the clearance between the extension and the outer barrel very small Passages for water or drilling fluid are provided by semicircular grooves in the walls of the coring bit This arrangement decreases the over-all wall thickness, and the Concore core barrel has a smaller kerf area than most double tube core barrels. A change-over disk in the core barrel head permits easy conversion from a double to a single tube core barrel The special core retainers consist of a heavy rubber sleeve for use in soil and very soft rock and a split ring with integral springs for use in soft to medium hard rock. The manufacturer has

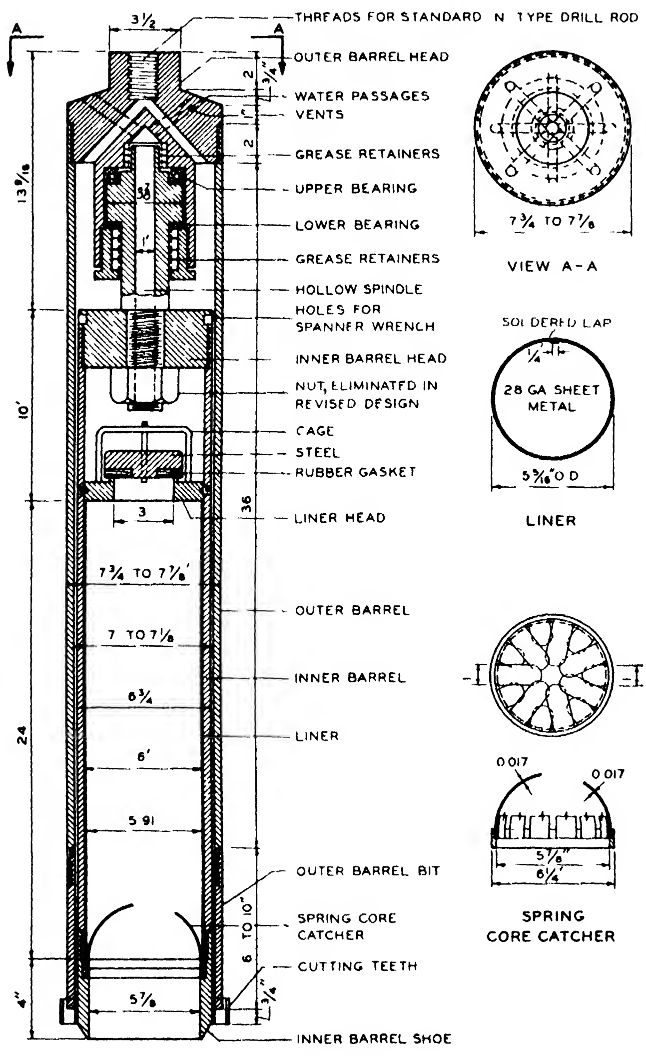


CONCORE DOUBLE TUBE CORE BARREL

FIG 268

recently experimented with hard chromium plating of the core barrel It was found that such plating decreased the friction between the core and inner tube to such an extent that danger of blocking is decreased and longer cores can be obtained, it also decreased the amount of work required for cleaning the core barrel and maintaining it in proper working condition

Flush or protruding inner tube.- The greatest protection of the core against erosion and transmission of torsional forces is obtained by letting the inner tube or its shoe extend to or a little below the teeth or inserts in the coring bit A core barrel of this type was designed and built by the Geotechnical Committee of the **Government Railways of Japan (930)** in 1936 and is described in the Preliminary Report by the Committee on Sampling and Testing (107) Independently thereof, a core barrel with protruding inner tube and specially adapted for sampling of dense but erodible soils was designed for the **Denison District**, Corps of Engineers, by **H. L. Johnson (143, 528)** and is known as the Denison core barrel, Fig 269



H L JOHNSON CIVIL ENGINEERING, 1940 VOL 10, P 346

DENISON DOUBLE TUBE CORE BARREL

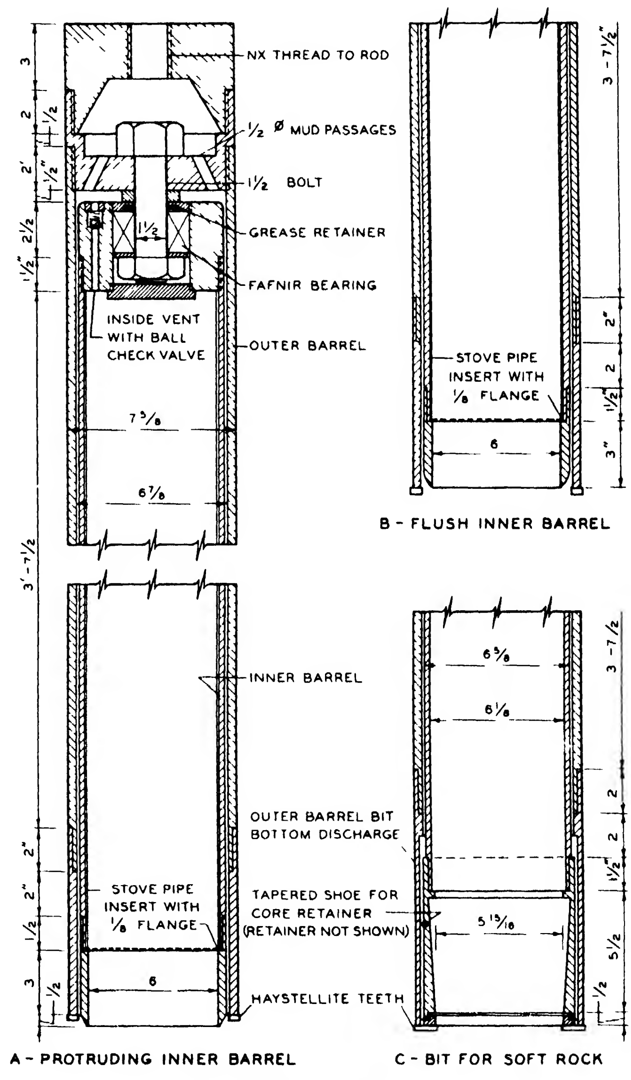
FIG 269

The inner tube of the Denison core barrel has a shoe with a sharp cutting edge. The extension of this cutting edge below the coring bit can be varied from zero to about 3 in by means of interchangeable coring bits of various lengths. The maximum extension is used in relatively soft or loose soils, and a cutting edge flush with the coring bit in very stiff, dense, and brittle soils A core retainer consisting of very thin and overlapping springs is placed in the joint between the shoe and the inner tube The thin springs offer less resistance to entrance of the core, cause less disturbance and offer better support of cores of cohesionless soils than a few heavier springs, but they are also more easily damaged, and frequent replacements of the core retainer are often required

The inner tube has a single seam liner of galvanized sheet metal, in which the core is preserved during shipment and storage.

A large disk check valve is provided above the liner, and an outside vent leads through the hollow spindle to the low pressure region above the sampler head. The hydrostatic pressure in the inner tube is thereby decreased and entrance of the core facilitated However, outside vents require careful control of the rate of feed and the pump pressure In case of excessive pump pressure or blocking by an excessive rate of feed, the circulating fluid may pass under the inner tube shoe, up through the tube and outside vents, and may thereby erode and remove most of the core The circulation of fluid should be decreased to a small amount or barely maintained while the core barrel is being seated on the bottom of the hole, and the flow should be increased slowly to its allowable value as the coring progresses and the length of the core increases

Minor modifications of the original design have recently been made by the **U. S. Bureau of Reclamation (518).** The lock nut below the inner tube head has been eliminated, and inexpensive liners of stove pipe are used when the samples are to be tested shortly after recovery The N size diamond core drill rods, commonly used, are replaced with 3-in double strength pipe, and the increased weight and stiffness of the drill rod tend to reduce whip and vibration of the core barrel



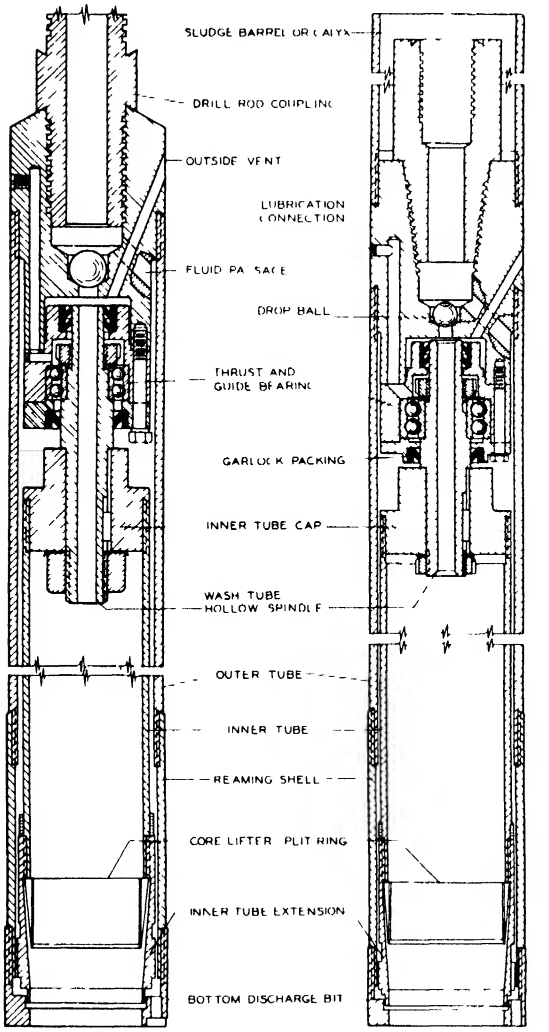
OMAHA DOUBLE TUBE CORE BARREL

FIG 270

The Denison core barrel has been used successfully in sand and silt above ground-water level, in stiff to hard clays and soft shale, and in soft and friable sandstone On the other hand, samples of fine sand taken below ground-water level are generally lost in spite of the overlapping core springs, and it has not yet been possible to obtain undisturbed samples of very coarse and

gravelly materials with this or any other type of core barrel, except when such soils are frozen before the coring

A core barrel, Fig 270, which in some respects is similar to the Denison core barrel, has been built and used extensively by the **Omaha District,** Corps of Engineers (115) For sampling of soils the inner tube has a stove pipe liner and a shoe with a cutting edge extending to or slightly below the coring bit A very small inside vent and ball check valve are provided in the inner tube head The hydrostatic pressure over the core will therefore be considerably greater than in the Denison

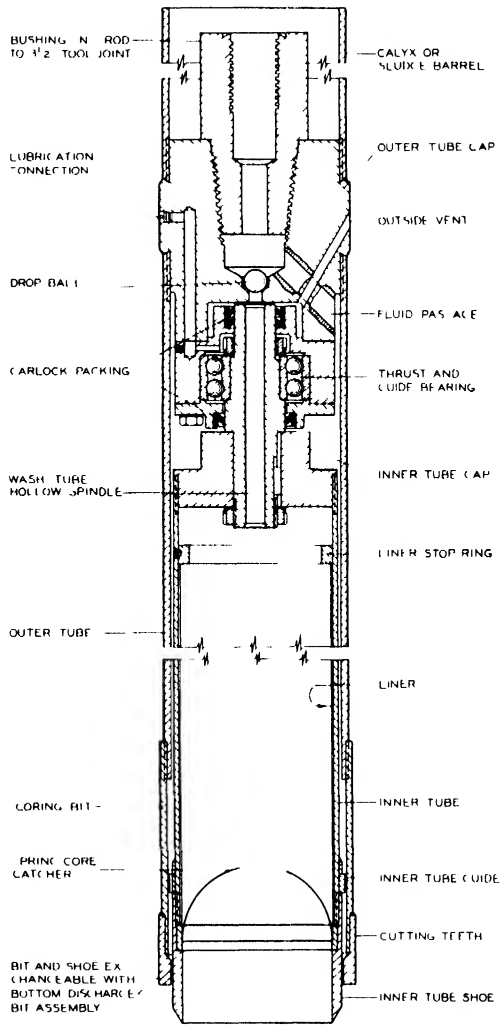


SIZE 2¾" X 3⅞"   4" X 5½" AND 6" X 7¾"

DIAMOND CORE DRILL MANUFACTURERS ASSOCIATION U S A

ASSOCIATION DOUBLE TUBE CORE BARREL

FIG 271



SIZE 6" X 7¾

E J LONGYEAR CO

COMBINATION SOIL AND ROCK CORE BARREL

FIG 272

core barrel, but there is no danger of bypassing the circulating fluid through the inner tube, and less careful control of the rate of feed and pump pressure is required. When the core barrel is used in soft rocks, the liner is generally omitted, the coring

bit exchanged with a regular bottom discharge bit, and the inner tube shoe replaced with an extension containing a split ring core catcher

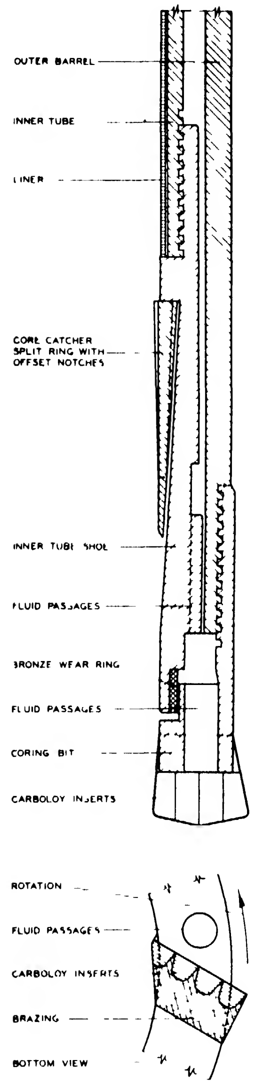
Proposed standard double tube core barrels.- As indicated in Section 13 1, tentative standards for double tube core barrels of medium large diameter have been proposed by the **Diamond Core Drill Manufacturers Association.** Assembly drawings of these core barrels have been made available to the Committee on Sampling and Testing through the courtesy of the **E. J. Longyear Co.** and are shown in Fig 271 Three standard sizes are proposed, providing cores 2-3/4, 4, and 6 in. in diameter, see also Fig 261 The core barrels have a bottom discharge bit and swivel type inner tube with special arrangement for lubrication of the ball bearing swivel head The inner tube has an extension which contains a core catcher unit and reaches nearly to the edge of the coring bit Outside vents, leading through the hollow spindle to the top of the core barrel head, are provided, and an additional vent in the center of the core barrel head permits flushing of the inner tube before the core barrel is seated at the bottom of the core hole After flushing, the central vent to the drill rod is closed by means of a drop ball, but this ball does not act as a check valve, and the pressure over the core during withdrawal will be equal to the fluid pressure at the level of the exits for the outside vents A check valve and reduction of pressure over the core during withdrawal could be obtained by use of a second and smaller ball, which is dropped first and closes the opening in the hollow spindle or wash tube

As proposed by the **E. J. Longyear Co.** and shown in Fig 272, the 6 in by 7-3/4 in core barrel in Fig 271 can easily be converted into a core barrel with protruding inner tube and liner for use in erodible soils

Setting of teeth in coring bit.- When starting coring operations in virgin territory, it is often necessary to experiment with various types of coring bits and bit settings before satisfactory results are obtained In general, a small number of relatively long teeth are preferable for coring of soft and sticky formations which tend to ball up the bit, whereas a large number of small teeth or cutters provides a greater rate of progress and causes less disturbance of the material when coring in hard formations However, sufficient systematic research has not yet been performed to permit formulation of detailed guiding principles in selecting the number, size, shape, and arrangement of cutters which will produce the best results in various types of soil and soft rock

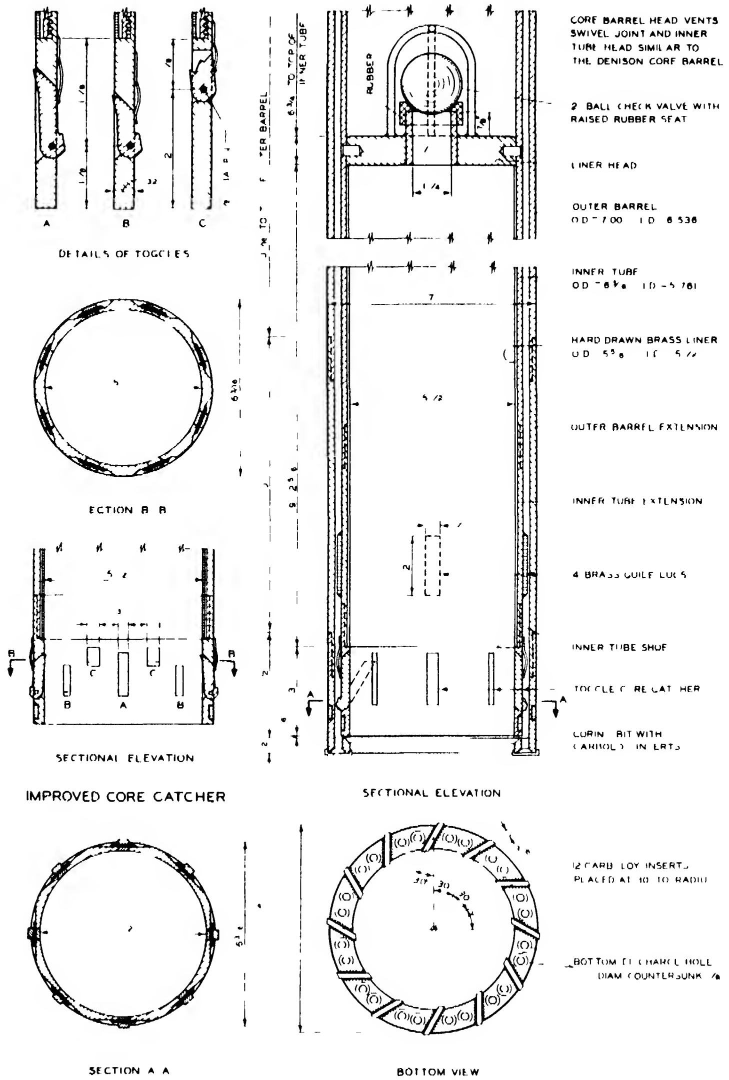
For use in soft formations, consideration may be given to a bit with teeth which are inclined with respect to the radius, so that a slicing rather than a scraping action is produced, and so that the cuttings are forced toward the outer rim of the bit where they are more readily removed by the circulating fluid Each tooth or cutter may be formed by a single, large, hard-metal insert or it may be composed of several inserts as shown in Fig 273A It is possible that a pointed or slightly dentated or irregular edge of each cutter will be more efficient than a straight and smooth edge A bit setting similar to that shown in Fig. 273A has been

used successfully by the **Waterways Experiment Station,** Corps of Engineers, in obtaining cores of Permian Red Beds, consisting of hard clay and soft shales with



BIT WITH INCLINED TEETH

FIG 273-A



SPECIAL ENGINEERING DIVISION THE PANAMA CANAL

FIG 273-B - PANAMA SOFT ROCK CORE BARREL

slickensides and interspersed streaks of silty sand and gypsum The coring experiments were performed by **A. L. Mathews,** assisted by an expert bit setter from the **George E. Failing Co.**

A similar coring bit with inclined teeth and special core catchers, Fig. 273B, has recently been developed by the **Special Engineering Division,** The Panama Canal (*).

(*) I C P Memo 65, "Experimental Drilling, Sampling, and Testing on Cucaracha Clay Shale and Atlantic Muck", Special Engineering Division, The Panama Canal, June 1948 The experiments were performed under direction of Colonel James H Stratton and conducted by Messrs T F Thompson and E J Zegarra, assisted by Messrs W H Bussey and M J Gleason The core catcher was designed by Mr L H Henderson, and the writer acted as consultant during the first part of the experiments

The cutters consist of 12 Carboloy inserts placed under an angle of 30° with the radius. The core catcher is formed by 8 toggles which in open position are flush with the interior of the liner and therefore do not disturb a core of soft material as it enters the inner tube. The upper part of the core barrel is similar to the Denison core barrel, but the seat of the check valve is raised above the liner head in order to decrease the danger of fouling by accumulated cuttings This core barrel and bit have been used successfully in obtaining 10-ft long cores in fault zones and soft parts of the Cucaracha formation, consisting of relatively soft but brittle clay shales with very pronounced slickensides This material is easily broken up by action of the coring bit and removed by the circulating fluid, and only short and disturbed cores were obtained before the new coring bit and core catchers were developed. On the other hand, when this bit is used in the harder and more abrasive rocks, the rate of progress is very small, and the bit rapidly becomes dull and plugged A bit with a large number of small inserts or diamonds is more efficient in such materials The greatest difficulties are encountered in formations consisting of alternating hard and soft strata, and experiments are in progress with the object of developing a bit setting which will produce satisfactory results under such conditions

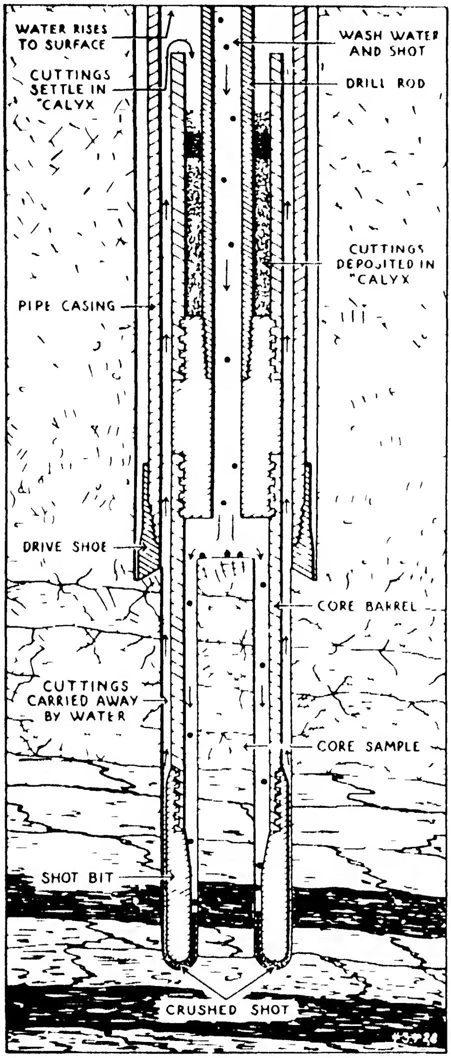
13.4 Shot Core Boring

This method derives its name from the use of chilled and very hard steel shot as a cutting medium The shot has a diameter of about 0 1 in and is also known under the trade name Calyxite The core barrels used in shot core boring consist of a single tube with an upset lower end or a detachable, slotted bit of mild steel. The figures in this section were obtained from catalogues furnished by the **Ingersoll-Rand Co. (139).**

General principles.- The general principles of shot core boring are shown in Fig. 274A and B. The steel shot is fed with the wash water and lodges around the lower part of the bit. During rotation of the barrel, the shot is crushed into sharp and highly abrasive particles, some of which become embedded in the mild steel bit The amount of shot introduced must be carefully controlled, since too much shot will cause the bit to ride on the steel balls without crushing them and grinding up the rock, whereas too little shot retards the rate of progress by not providing a sufficient number of cutting surfaces The flow of wash water must be regulated so that it removes the rock cuttings but not the heavier steel particles

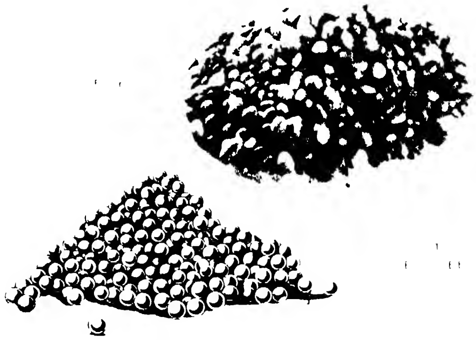
The rock cuttings are carried up along the outside of the barrel with the return flow of wash water, but above the barrel the flow area is increased and the velocity decreased to such an extent that the water cannot carry the cuttings to the surface of the hole without increasing the flow of wash water above the value which causes removal of the shot from the bit. A sludge barrel or calyx is therefore attached to the top of the core barrel, and the rock cuttings are deposited therein. The cuttings constitute a fairly representative sample of the material at the bottom of the hole and may be used as such when a core is not recovered Since shot core

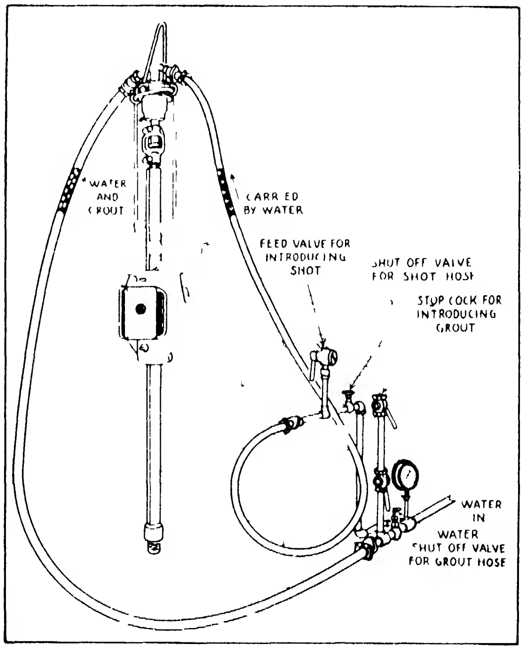
boring in deep bore holes is made possible by providing the core barrel with a calyx, the method is also called calyx core boring The calyx also makes it possible to operate with the bore hole partially instead of completely filled with water



PRINCIPLE OF SHOT CORE BORING

FIG 274-A





SHOT AND GROUT FEED ARRANGEMENTS

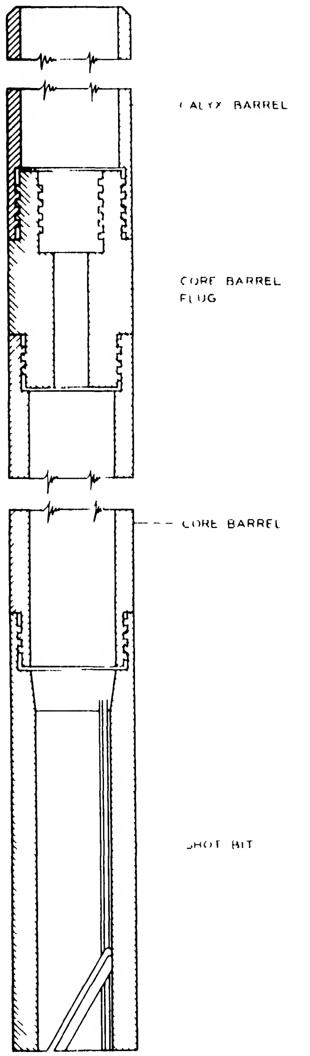
FIG 274-B

Details of shot core barrels.- Typical shot core barrels of small and medium diameter are shown in Fig 275A and B The inclined slot or slots in the bit facilitate passage of shot to the bottom and outside of the bit The principal dimensions of these core barrels are given in Table 9 Intermediate and larger sizes are also furnished, and the barrels can be obtained in lengths from 2 to 10 ft The diameter of the core is about 1/8 in smaller than the inside diameter of the bit, and the smallest core is therefore 1-5/8 in in diameter Shot core barrels for drilling holes 36 to 48 in in diameter are shown in Fig 275C The short barrel at

TABLE 9
DIMENSIONS OF SMALL AND MEDIUM SHOT CORE BARRELS

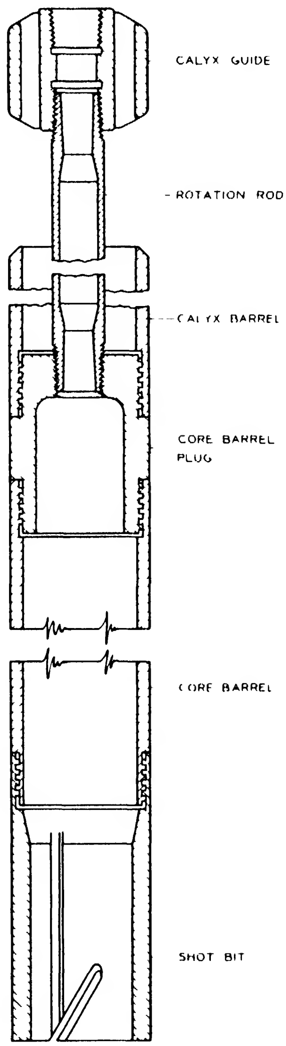
	Fig 275A		Fig 275B		
OD Barrel, In	2-3/8	3-1/2	4-1/2	8-5/8	12-3/4
ID Barrel, In	1-15/16	2-29/32	3-53/64	7-63/64	12-0
OD Bit, In	2-1/2	3-1/2	4-1/2	8-5/8	12-3/4
ID Bit, In	1-3/4	2-3/4	3-5/8	7-5/8	11-3/4

Data from catalogues by the Ingersoll-Rand Co



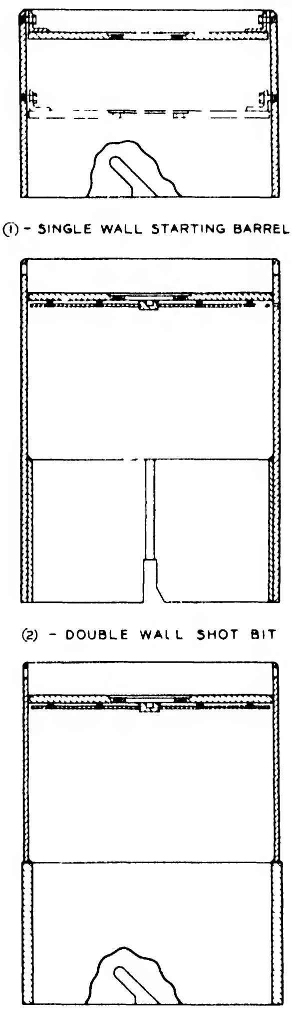
INGERSOLL-RAND CO NEW YORK N Y

SMALL SHOT CORE BARREL
FIG 275-A



INGERSOLL RAND COMPANY NEW YORK N Y

MEDIUM SHOT CORE BARREL
FIG 275-B



(1) - SINGLE WALL STARTING BARREL

(2) - DOUBLE WALL SHOT BIT

(3) - SINGLE WALL HEAVY SHOT BIT

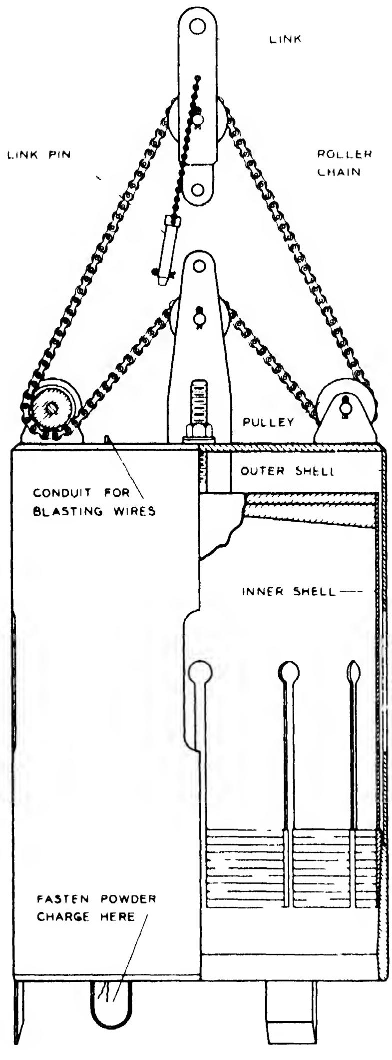
INGERSOLL RAND COMPANY NEW YORK N Y

LARGE SHOT CORE BARRELS
FIG 275-C

top, (1), has an adjustable head plate and is used only for starting the hole when the rock extends to the ground surface or the drilling machine The regular large-diameter core barrels, (2) and (3) in Fig 275C, have a bit with a wall thickness of

7/8 to 1-3/8 in , formed by welding an inner tube, (2), or a short section of heavy-wall pipe, (3), to the main barrel Connection to the drill pipe is made by a flange coupling, bolted to the head plate, only the bolt holes are shown in the figures The thin plate below the head plate in (2) and (3) is held in place by a series of spacer bolts, and a strong radial flow of wash water in the narrow space between the two plates serves to distribute the shot along the circumference of the core, and to prevent its forming a pile on top of the core

Operation.- Shot core barrels may be operated with a light rotary drilling rig, Fig 37, or regular skid mounted drilling machines, Fig 127, but special drilling machines, Fig 128, are generally used, especially for shot core barrels of medium and large diameter Calyx core drill rods, Fig 172, are used in holes up to 4-1/2 in in diameter and A P I drill pipe, Fig 173, in larger holes The drill pipe for large core barrels is generally provided with guides in order to decrease the whip, and the standard couplings are often replaced with flanged couplings, having slots instead of bolt holes, since the pipe is subjected to very large torsional moments, and it is then difficult to disconnect standard screw couplings



CORE LIFTER FOR LARGE CORES

FIG 276

Small and medium sized cores are broken off and retained in the core barrel by adding screened, small beach pebbles -- called grout, Fig 274B -- to the wash water just before withdrawal and in such amounts that the space between the core and the bit becomes packed with grout Cores of large diameter cannot be broken off and retained in the above mentioned manner, and the core barrel is then withdrawn empty and replaced with another barrel with a core catcher and blasting caps attached to the lower edge of the barrel, Fig. 276. The core may also be broken free with wedges, and a small hole drilled in the top of the core for insertion of a wedge pin or expansion eye bolt by means of which the core is hoisted to the surface. A final "mucking-up" of broken and lost parts of the core is often required

When the diameter of the hole is greater than 48 in. and the depth more than 250 to 300 ft, it is generally more economical to eliminate the heavy drill rods and use the rodless core boring method. The core barrel with an electrically driven rotation unit is lowered into the hole by a cable, and the

rotation unit is anchored to the sides of the hole by means of a torque anchor After an advance of 6 to 7 ft, the core barrel and rotation unit are withdrawn and replaced with a core lifter barrel by means of which the core is broken off and removed Shafts up to 6 ft in diameter and 1000 ft in depth can be drilled by this method

General comments.- Shot core boring can be used only for drilling in a downward direction and is most efficient when the hole is vertical In inclined holes the shot has a tendency to collect on the lower side of the bit, but the method is frequently used in holes with inclinations up to 30 degrees and occasionally up to 45 degrees The best results are obtained in sound rock, neither too hard nor too soft, which is not eroded or otherwise affected by the circulating water The shot tends to become embedded in soft rock instead of grinding it up, and the progress in hard rock is slow, especially when compared with that of diamond core drilling The method is not suitable for use in broken and cavernous rock, since the shot is lost in the fissures and cavities

Shot core boring subjects the core to large torsional stresses, and cores of small diameter can be obtained only in sound and fairly strong rock From the standpoint of efficiency and cost, shot core boring is best suited for taking cores 4 in or more in diameter, and it is the most widely used method for obtaining cores of very large diameter and for drilling accessible bore holes in rock

13.5 Diamond Core Boring

Except for size and the use of diamonds as a cutting medium, diamond core barrels do not differ in principle from core barrels with metal teeth, and they are built both as single and double tube barrels, with or without a swivel head for the inner tube A special coupling, called a reaming shell or a swell coupling, is generally inserted between the coring bit and the outer barrel Diamonds or inserts with diamonds are usually embedded in the surface of the reaming shell, Fig 277F, which serves to keep the bore hole true to gage The special casing used in diamond core boring, Fig 169, is provided with a drive shoe or a diamond casing bit The latter is similar to the coring bit and facilitates advancing the casing through swelling and broken formations

Coring bits with hard steel teeth, called saw tooth bits, are often used on diamond core barrels for drilling through hard soils and very soft rock, and coring bits in which the diamonds are replaced with inserts of tungsten carbide alloys are used to some extent in soft and medium hard rocks Such bits are cheaper than diamond bits, and a satisfactory rate of progress may be obtained with them in some formations However, reports on the efficiency of tungsten carbide bits in harder rocks vary, and it is claimed that they tend to lose their gage, so that expensive reaming is required before a new and full-gage bit or casing can be inserted in the hole

The figures in this section were obtained from catalogues, papers, and

memoranda furnished by **E. J. Longyear Co. (152), J. K. Smit & Sons, Inc. (172), Sprague & Henwood, Inc. (175), Sullivan Machinery Co. (180),** and **Boyles Bros. Drilling Co. Ltd. (187).**

Diamonds.- Two types of diamonds are used in diamond coring bits, the black diamonds which are called carbons or carbonados, and the gray, yellow, brownish industrial diamonds, known as bort or bortz The principal difference between the two types is not the color but the crystalline structure High quality bortz may be slightly harder than carbons but have distinct cleavage planes and often chip and split under pressure and impact, whereas carbons have no cleavage planes and are much more durable than bortz

Formerly carbons alone were used in diamond coring bits, but the price rose steadily from about $2 per carat in 1870 to a maximum of $150 to $200 per carat for large stones in 1930, since then the price has fluctuated and has at times decreased to $70 to $80 per carat In contrast thereto, bortz cost only $4 to $8 per carat in 1947 The initial cost of a carbon bit, containing 6 to 8 stones of about two carats each, plus wear, loss, and theft of stones represents a large part of the total cost of diamond core drilling operations With the development during the last decade of economical and reliable methods for mechanical setting of stones in diamond bits, small industrial diamonds can be used to advantage, and the cost of bortz coring bits has been decreased to 1/10th to 1/25th of the cost of a comparable carbon bit The result is that bortz instead of carbons now are used in the great majority of diamond coring bits

Hand-set coring bits.- Carbon coring bits are hand set and usually contain 6 to 8 stones of about two carats each, but a smaller or greater number may be used according to the size of the bit and the stones Holes are drilled in the inner and outer edges of the blank steel bit, the carbons are placed in the holes, and the steel is hammered or peened in around them, Fig 277A

The first bortz bits were hand set as the carbon bits but smaller stones and a larger number were used, Fig 277B The cost of the initial setting is thereby increased, and frequent resetting is necessary on account of chipping and splitting of the stones As a consequence, the services of an expert diamond setter are required for each two or three operating drilling crews

Mechanically-set coring bits.- The above mentioned disadvantages of bortz coring bits have been eliminated by the development of suitable matrices and of mechanical methods for setting the stones therein. The matrix is varied according to the purpose of the bit and the method of setting the stones, and it may consist of manganese bronze, beryllium copper, or tungsten carbide alloys. Several methods of mechanical setting have been developed, but the general procedure is to prepare a mold with holes for the individual diamonds, which are placed therein and held in position by a partial vacuum below the mold and by spraying with a quick-drying cement The mold is then filled with molten matrix, which must have a melting

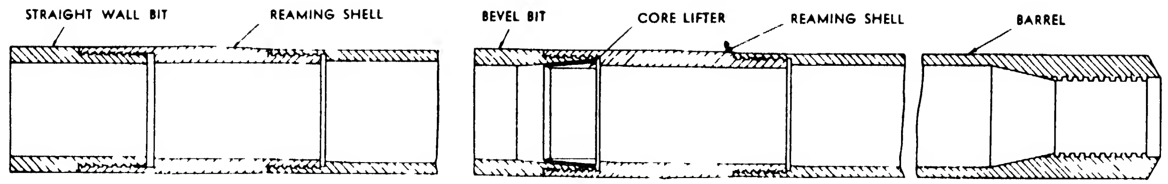
point below 1800 to 1900 degrees Fahrenheit, or with powdered matrix which thereafter is compressed and sintered. Sintered matrices are the hardest and generally the best suited for use in broken and coarse-grained rocks which produce large, hard, and abrasive cuttings Cast-set bits with a somewhat softer matrix are preferred for use in softer, uniform, and fine-grained rocks, since the matrix gradually wears away, thereby exposing the diamonds and keeping the bit sharp and free cutting

The cost of hand setting is materially decreased when the bit is flat faced, but with mechanical setting the rounded or contour faced bits can be produced without extra cost except for that of the increased number of diamonds Grooves or waterways across the face and along the sides of the bit are often provided for bits to be used in soft formations but are generally omitted when the bits are to be used in hard rock

DIAMOND DRILL BITS

FIG. 277

A mechanically-set bortz bit may contain from fifty to several hundred small stones, and the influence of chipping, splitting, and loss of individual stones is thereby decreased The entire crown of the bit may consist of matrix with diamonds, Fig 277C, or the diamond studded matrix may be formed and used as inserts, Fig 277E When the bit becomes dull on account of polishing, chipping, splitting, and loss of diamonds, the matrix is dissolved with acid, and the sound stones are reset in a new matrix The low cost of mechanically-set bortz coring bits makes it possible to keep a sufficient number on hand while the worn out bits are shipped to the factory for resetting, and the need of a diamond setter in the field is then eliminated



SULLIVAN MACHINERY COMPANY

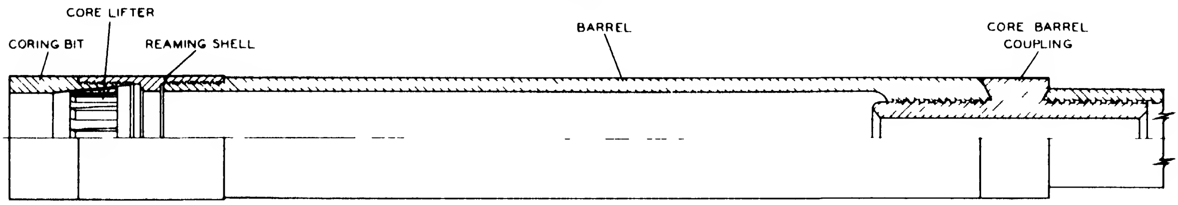


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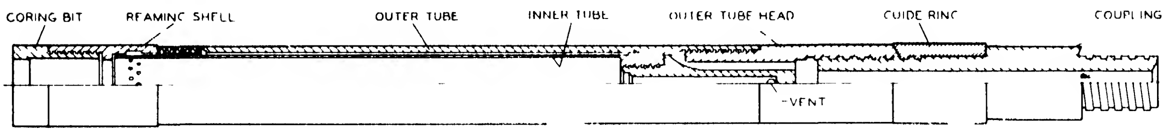
FIG 278 - SINGLE TUBE DIAMOND CORE BARRELS



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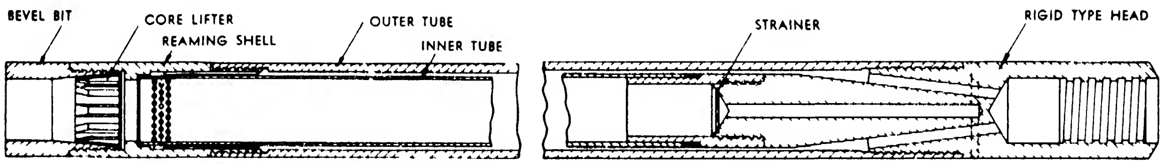

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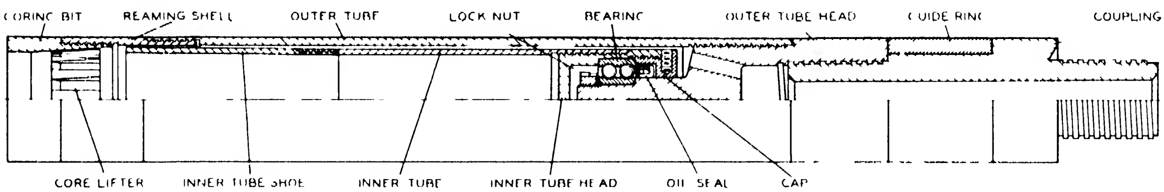
FIG 279 - DOUBLE TUBE RIGID DIAMOND CORE BARRELS



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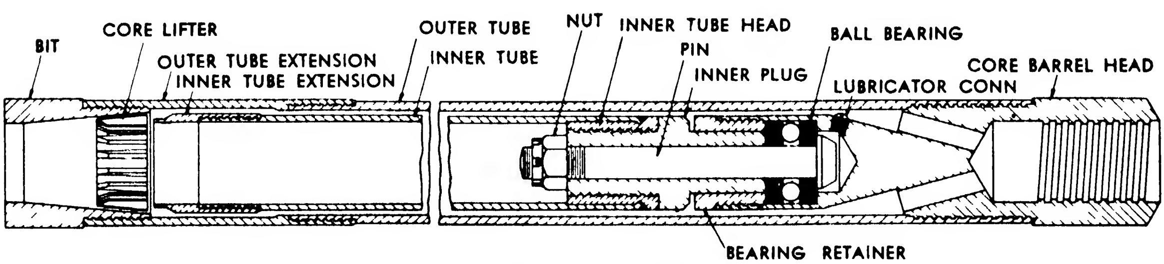

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FIG 280 - DOUBLE TUBE SWIVEL TYPE DIAMOND CORE BARRELS

Diamond impregnated coring bits.- In sintered bits the diamonds are in some cases mixed with the powdered matrix so that the entire matrix becomes impregnated with diamonds, Fig 277D This method has the advantage that it permits use of chips and stones so small that they otherwise would be discarded, and that the bit can be used without resetting until the entire matrix and all the diamonds are used up Diamond impregnated bits have been used with good results in some types of rock whereas in other formations these bits tend to become polished and dull The bit may be sharpened by blasting with carborundum grit which wears away the matrix and exposes the diamonds, but polished stones may still decrease the efficiency of the bit

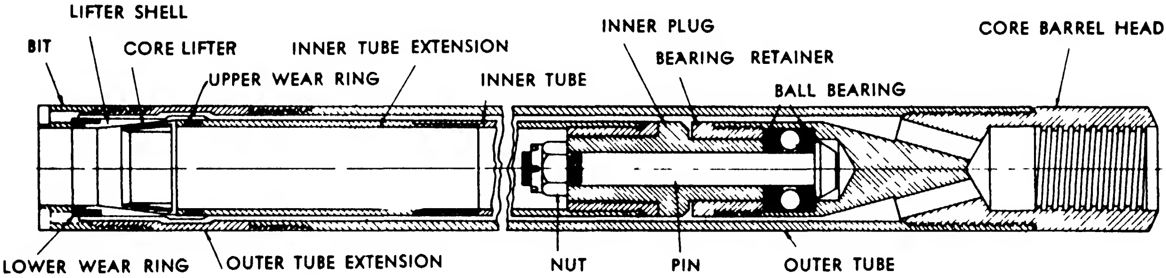
Solid or non-coring bits.- When drilling through rock of which a core is not required, the diamond coring bit may be replaced with a solid diamond bit, Fig 277G. The fastest progress in soft to medium hard rock is obtained with a concave bit, but the pilot bit is generally preferred in hard rock, since the pilot then serves as a guide, decreases whip and vibration of the bit and drill rods, and reduces the danger of deviation of the hole During the actual drilling, the rate of progress obtained with a solid bit is smaller than that obtained with a coring bit of the same outside diameter However, it is not necessary to withdraw a solid bit before the hole is completed or the bit is dull, whereas a coring bit and barrel must be withdrawn when the barrel is filled or blocked by the core Furthermore, a solid bit can be used for drilling holes with a smaller diameter than that considered as a practical minimum when coring bits are used Solid bits with a diameter of only 1-3/16 in are frequently used Solid, mechanically-set, bortz bits are used extensively for blast hole drilling in mining operations, especially in formations of which it is difficult to obtain long cores and where the use of a coring bit and barrel would require frequent withdrawals to remove the core On the other hand, a coring bit and barrel provide faster over-all progress in formations of which long cores can be obtained, at least when the rock is very hard

Diamond core barrels.- Examples of the principal types of diamond core barrels are shown in Fig 278-281 The simplest of these is the single tube core barrel, Fig 278, which is used only in fairly strong, sound, and uniform rock, not subject to erosion by the circulating fluid The inside of the coring bit may be straight, for use in materials which can be retained by dry-blocking, or bevelled to accommodate a split ring core catcher It is generally advisable to use a core catcher since dry-blocking may damage the gage stones on the inside rim of the coring bit

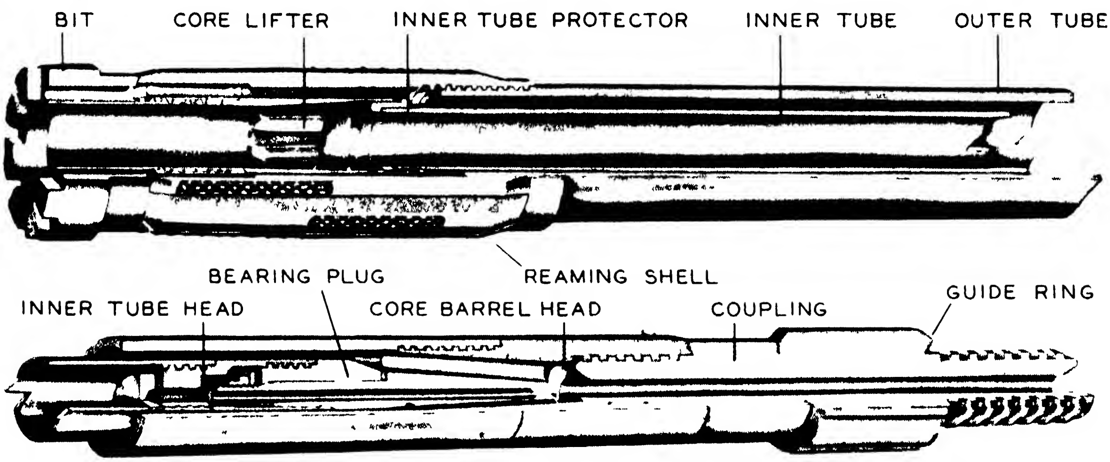
Partial protection against blocking of the fluid passages and erosion of the core is obtained with double tube, rigid type core barrels, Fig 279, with an inner tube which is rigidly connected to the core barrel head and rotates with the outer tube. A straight-wall or a bevel-wall bit may be used according to the character of the rock The inner tube is generally provided with outside vents, and a large number of small holes is drilled through the lower end of the tube A small amount

of water flows through these holes, up along the core, and through the outside vents Accumulation of cuttings, the inside friction, and transmission of torsional forces to the core are thereby decreased, but in case of outside blocking or excessive pump pressure, there is also danger that too large a part of the circulating fluid may be diverted up through the inner tube and the outside vents and cause erosion of the core.

Better protection of the core is obtained with double tube, swivel type core barrels, Fig 280, in which the inner tube does not rotate with the outer tube The core barrels shown in the figure have ball bearing swivel heads and inner tubes



SULLIVAN MACHINERY COMPANY



BOYLES BROS DRILLING COMPANY LTD

FIG 281 - DOUBLE TUBE DIAMOND CORE BARRELS WITH BOTTOM DISCHARGE

without vents, but some manufacturers use fiber thrust bearings and provide vents through the spindle and sampler head The advantages and disadvantages of inner tubes with and without vents have been discussed in Section 13 3

The best protection of cores of relatively soft and erodible materials is obtained with a double tube, swivel head core barrel with a bottom discharge bit, Fig 281 The fluid passages in these core barrels are generally larger than in other diamond core barrels in order to permit use of drilling fluid instead of water To decrease the danger of mudding up of the bit and of outside blocking, the Boyles Bros core barrel, Fig 281 bottom, has grooves across the face of the bit, a fluted reaming

shell and guide ring, and the diameter of the outer tube is decreased

The core barrels are furnished in lengths of 5, 10, 15, and 20 ft Some single tube core barrels are divided into 5-ft long sections so that the length can be changed as required by the rock conditions encountered Starting barrels or core barrels with a length of 1 to 2 ft are used in starting the boring when rock extends to ground level and the core barrel is so large that it cannot pass through the feed screw or the drive rod of the drilling machine

Standard sizes.- The **Diamond Core Drill Manufacturers Association,** in cooperation with interested organizations and agencies and under sponsorship of the **National Bureau of Standards,** U S Department of Commerce, adopted in 1930 a commercial standard for diamond core drill fittings, CS17-30 This standard was revised in 1932, 1942, and in 1947 (156) Details of diamond core drill casing and drill rods as specified in the latest revision of the standard, CS17-47, are given in Fig 169 and 170, see also Fig 261 A summary of the principal dimensions, given in and reprinted from CS17-47, is presented in Table 10

TABLE 10 - NOMINAL DIMENSIONS OF DIAMOND CORE DRILL FITTINGS

Size Designation		Casing	Casing Coupling		Casing Bit	Core Barrel Bit	Drill Rod	Diam of Hole by Core Barrel Bit*	Approx Diam of Core
Casing, Coupling and Bit Core Barrel Bit	Drill Rod and Coupling	OD	OD	ID	OD	OD	OD		
		in	in	in	in	in	in	in	in
EX	F	1-13/16	1-13/16	1- 1/2	1-27/32	1- 7/16	1- 5/16	1-1/2	0-7/8
AX	A	2- 1/4	2- 1/4	1-29/32	2- 5/16	1-27/32	1- 5/8	1-7/8	1-1/8
BX	B	2- 7/8	2- 7/8	2- 3/8	2-15/16	2- 5/16	1-29/32	2-3/8	1-5/8
NX	N	3- 1/2	3- 1/2	3- 0	3- 9/16	2-15/16	2- 3/8	3- 0	2-1/8

* Assuming hole 1/32 in larger than bit and listing diameters to nearest 1/8 in

The dimensions given in the standard are so determined that minimum clearance is provided for passage of the coring bit and for insertion and telescoping of the various sizes of casing The NX bit will pass through NX casing and drill a hole which will admit BX casing, and the BX bit will pass through this casing and drill a hole large enough for AX casing, etc Larger core barrels with bits up to 4-7/8 in OD are carried in stock by some manufacturers, and still larger core barrels or bits are made to order The large diamond core barrels are used primarily in exploration for oil and are called the oil field type, they have large fluid passages to permit use of drilling fluid instead of water The Canadian standard for diamond core drill fittings is practically identical with the U S A standard but includes both a smaller and a larger size, the XR size provides cores with a diameter of 3/4 in and the H size cores of 2-7/8-in diameter

Operation.- Reference is made to Sections 4 17 and 4 19 for a brief review of drilling machines and of the general principles governing the operation of core barrels; only a few additional comments will be made here

Clear water is generally preferred to drilling fluid in operation of diamond core barrels in sound rock Water is cheaper and requires smaller fluid passages or smaller pump pressures, and the rock cuttings are generally so fine that they remain in suspension in the drilling fluid and do not settle out in the sump As coring progresses, the unit weight and viscosity of the drilling fluid is therefore increased and its carrying capacity decreased Furthermore, in many mining explorations it is desirable to collect all the cuttings, which are treated as a representative sample and assayed, but this cannot be done when drilling fluid is used and the cuttings remain in suspension therein However, drilling fluid is used for diamond core boring in the oil fields and in general when required to prevent excessive caving of deep bore holes, but core barrels with large fluid passages are then used

Carbon coring bits are operated under relatively high feed pressures and low to moderate bit speeds, 250 to 500 rpm, whereas modern bortz coring bits are operated with bit speeds up to 800 and 1200 rpm and occasionally 1750 to 2000 rpm in hard rock These speeds apply primarily to small coring bits, EX and AX, and they are decreased with increasing diameter of the bit Much higher coring bit speeds have been attained in experiments under laboratory conditions, and speeds of 3000 to 4000 rpm are often used in blast hole drilling with non-coring diamond bits Very high speeds of rotation require dynamically balanced equipment and carefully aligned drill rods As the equipment becomes worn, it is generally necessary to decrease the bit speed in order to avoid excessive vibration, whip, and chattering of the bit with consequent danger of breaking the core and damaging the bit

The allowable feed pressure for bortz coring bits with relatively large stones is smaller than for carbon bits, since high pressures may cause chipping and splitting of the stones However, modern mechanically-set bits with very small stones can withstand and are often operated under high feed pressures Although reports and opinions vary, it seems that in hard rock the high feed pressure not only increases the rate of advance but also keeps the bit sharp and free cutting, whereas a low feed pressure in the same rock tends to polish the stones In other rocks the best results may be obtained with relatively low feed pressures The increase in speed of rotation, combined with relatively high feed pressures and a greater number of sharp cutting points on modern, mechanically-set bortz bits, has increased the rate of advance in some formations to two or three times that formerly obtained with hand-set carbon or bortz bits Most of this increase in efficiency has been attained in the last decade

Advantages and use.- In comparison with shot core barrels and coring bits with relatively large hard-metal teeth or inserts, diamond coring bits provide a greater rate of progress in hard rock, subject the core to smaller torsional stresses, produce cores with a smoother surface, and make it possible to obtain longer cores

or cores of smaller diameter The smaller core barrels require in turn only relatively light, compact, and portable operating equipment, and diamond core boring can be carried out in any direction, downward, sidewise, and upward Therefore, when cores of small diameter are adequate, diamond core boring is generally preferred for exploratory borings in hard rock, especially in regions difficult of access and when the available space is restricted, as in tunnels

Diamond core boring is also the method most commonly used in extending foundation explorations into medium hard and hard rock, provided cores of large diameter are not required for testing or other reasons Sizes NX and BX core barrels are often preferred for such explorations, since they provide better core recoveries than the smaller AX and EX core barrels when weak and broken formations are encountered Diamond studded or diamond impregnated inserts are also being used to an increasing extent for coring bits of large diameter, although hard-metal teeth and inserts or shot core barrels, on account of low first cost, generally are preferred for foundation exploration in soft to medium hard formations when cores with a diameter greater than 3 to 4 in are required

Considering the scope of this report, only a general outline of the principles of diamond core boring has been given in this section For further details reference is made to the various papers on the subject listed in the classified bibliography, especially in Section 10 under Additions to Section 7 Attention is called to a very complete bibliography of diamond drilling, compiled by the **Longyear Company (253).**

CHAPTER 14
SAMPLING IN SEARCH OF OIL AND MINERALS

14.1 General

The methods used in exploration and sampling of mineral deposits differ only in minor details from the methods used in foundation explorations Borings in sand and gravel deposits, in search of gold, platinum, tin, etc , are generally performed by the percussion or cable-tool method Great care is taken to preserve all the material removed from the bore hole between certain depths and in measuring the actual volume of the hole between these depths in order to obtain reliable data for determination of the yield of the deposit

Diamond core boring is used in the great majority of mining explorations in rock Although the diamond coring bit causes a minimum of disturbance of the material, the core recovery in broken and irregular formations, frequently encountered in or near ore bodies, is often low with important parts of the core ground up and removed by the circulating water In such cases the core alone does not constitute a representative sample, and great care is taken to collect all the cuttings in the wash water after each coring operation Likewise, when shot core boring occasionally is used, the cuttings deposited in the calyx are usually preserved and assayed In some instances where the borings are very deep and the rock not too hard, it has been found advantageous to use the equipment, especially the wire-line core barrels, developed in drilling for oil

The great depths to which explorations for oil are carried, the availability of heavy operating equipment, the time required for insertion and withdrawal on long strings of heavy drill pipe, swelling caused by expansion of gases entrapped in the core, deviations of the bore hole, etc , have caused development of a great variety of special sampling and surveying equipment and methods A brief review of the principal types of this equipment and these methods is presented in the following sections, since both the special core barrels and the methods of surveying occasionally have been and may be used to advantage in subsurface explorations for civil engineering purposes

With the decrease in cost and increase in efficiency of diamond coring bits in recent years, diamond core barrels of large diameter and great length are being used to some extent when hard rock is encountered in deep borings for oil The diamond coring bit provides a greater rate of progress, cores of larger diameter for a given hole diameter, and much longer cores of hard rock than can be obtained

with bladed or roller coring bits Brantley (205) reports that diamond core barrels up to 90 ft in length are being used in deep oil wells

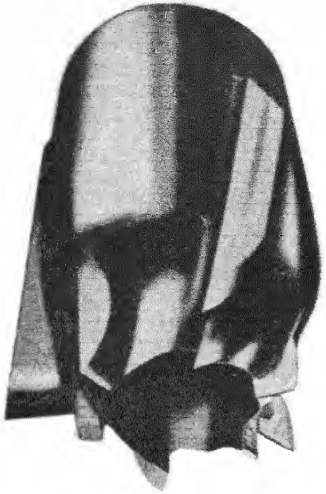
The majority of the figures in this chapter were obtained from the "Composite Catalogue of Oil Field and Pipe Line Equipment", published by **The Oil Weekly** (183) and from catalogues furnished by the **Hughes Tool Company** (129 and 130), the **Reed Roller Bit Company** (167 and 168), **Sperry-Sun Well Surveying Co.** (173), and the **Eastman Oil Well Survey Corp.** (118).

14.2 Regular Rotary Core Barrels

Rotary core barrels used in the oil fields generally have coring bits, Fig 282, which are similar to the rotary drilling bits shown in Fig 43-44 Bladed cutters are used in soft or broken formations and roller cutters in hard formations Both types are available with various forms of the blades, and with rollers having different numbers, size, and shape of teeth, each type is adapted for use in particular formations

The regular rotary core barrels are double tube barrels with bottom discharge bit, typical examples and details are shown in Fig 283-288 The inner tubes are the so-called floating type which do not rotate with the outer barrel and are guided by small ribs or vanes near the top and bottom An upward movement of the inner tube in the Reed core barrels, Fig 283, is prevented by a rubber thrust bearing in the core barrel head, whereas the inner tubes in the Hughes core barrels, Fig. 284 and 285, are held in position by a slotted ring, welded to the inner tube and engaging a groove in the outer barrel A regular inside vent and ball check valve, Fig 283B, are used in ordinary coring operations, but outside vents, Fig 283A and 284, are preferred when coring in soft formations An inside vent with a drop ball check valve, Fig 285, is used when a considerable amount of cuttings has accumulated at the bottom of the hole and it is necessary to flush the inner tube and the hole before starting the actual coring operation The Reed core barrel with a regular inside vent and check valve, Fig 283B, is easily converted into the drop ball type by removing the inside vent tube

The core retainer is usually of the valve or toggle type, but it is often combined with a spring type retainer, Fig 287 A spring type core catcher with overlapping, tapered, helical springs, Fig 233C, is used in fine sand, whereas a conical, split ring core retainer combined with the toggle type often is used when the core consists of hard rock The Reed core barrels are provided with a core catcher protector, Fig 283A, consisting of a section of notched tubing, which holds the valves and springs in open position until the core enters the barrel and prevents foreign material from being lodged behind the valves and springs The Hughes core barrels are provided with a core barrel plug, Fig 286, fastened to the core catcher unit with soft iron rivets, which are sheared off when the barrel is seated on the bottom of the hole The core barrel plug not only holds the valves and springs



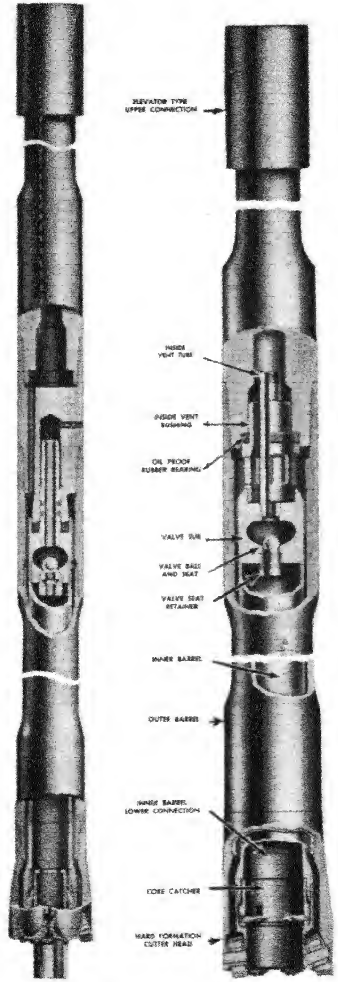
A-SOFT FORMATION BIT

B-HARD FORMATION BIT

REED ROLLER BIT CO.

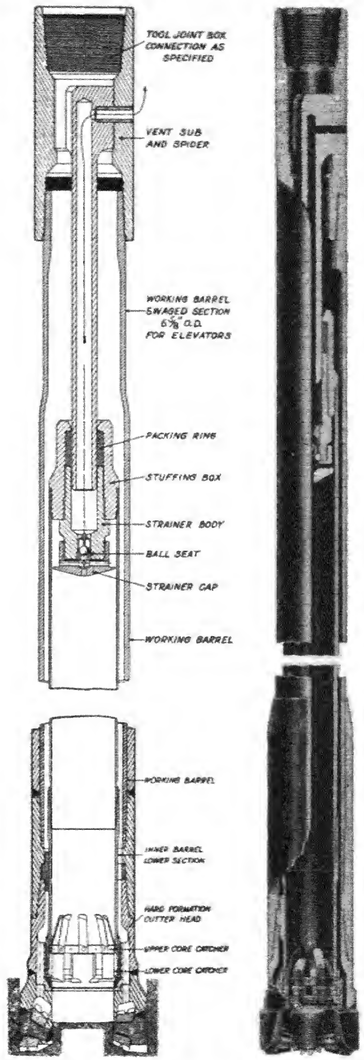
ROTARY CORING BITS

FIG. 282



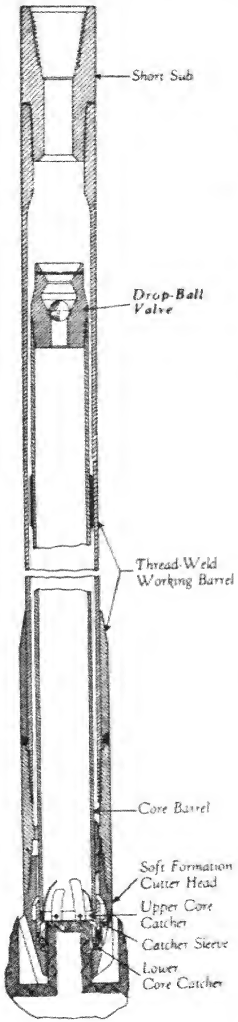
REED ROTARY CORE BARRELS

FIG. 283



HUGHES ROTARY CORE BARRELS

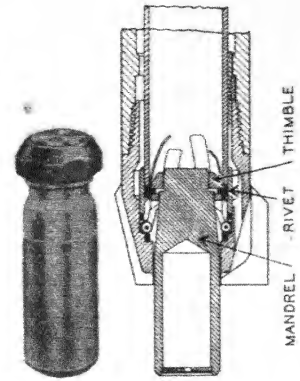
FIG. 284



HUGHES TOOL CO.

CORE BARREL WITH DROP BALL

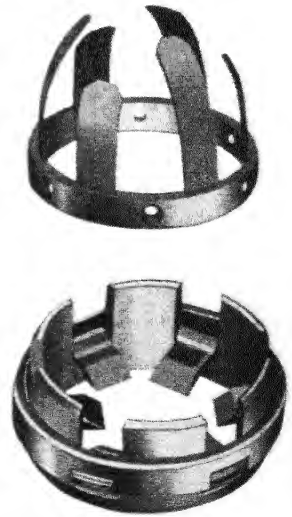
FIG. 285



HUGHES TOOL CO.

CORE BIT PLUG

FIG. 286



HUGHES TOOL CO.

CORE CATCHERS

FIG. 287

in open position until the core enters, but it also prevents cuttings and foreign material, accumulated at the bottom of the hole, from entering the core barrel

The kerf area of these core barrels is very large and the diameter of the cores relatively small in comparison with the diameter of the hole, as shown in Table 11 The standard length of the inner tube is about 20 ft, although 30-ft long tubes occasionally are used, but shorter barrels with 5-ft and 10-ft long inner tubes are also furnished

TABLE 11
DIAMETERS OF REED REGULAR ROTARY CORE BARRELS

Size of Bit Diameter of Hole in.	OD Outer Barrel in	OD Barrel Head in	Diameter of Core in
3-7/8 to 4-1/2	2-7/8	3-3/8	1-1/4
4-5/8 to 5-3/8	4- 0	4-1/4	2-1/4
5-1/2 to 6- 0	4- 0	4-5/8	2-3/8
6- 0 to 7-1/2	5- 0	5-1/2	3- 0
7-5/8 to 9-1/2	5-9/16	6-1/2	3-3/4
9-5/8 to 11-7/8	7-3/8	8-1/2	5-1/4
12- 0 to 16- 0	8-5/8	9-3/4	5-1/2

Data from catalogues by the Reed Roller Bit Co

The bit is set to cut the core with liberal clearance between the core and the inner tube, and the length of core which can be obtained in a single operation is therefore not limited by continuous friction between the core and the tube but by breaking of the core and wedging and jamming of individual pieces and sections To eliminate or decrease the influence of breaking and blocking and to obtain longer cores in broken formations, the Johnston-Soll core barrel, Fig 288, is provided with five telescoping liner sections, each accommodating a 4-ft long core When the core becomes blocked in one liner section, this section is simply pushed upward, and the danger of further blocking is decreased since the clearance between the core and the next liner section is increased On account of the telescoping liner, the cores obtained with the Johnston-Soll core barrel are from 1 to 2 in smaller in diameter than the cores obtained with the Reed or Hughes rotary core barrels

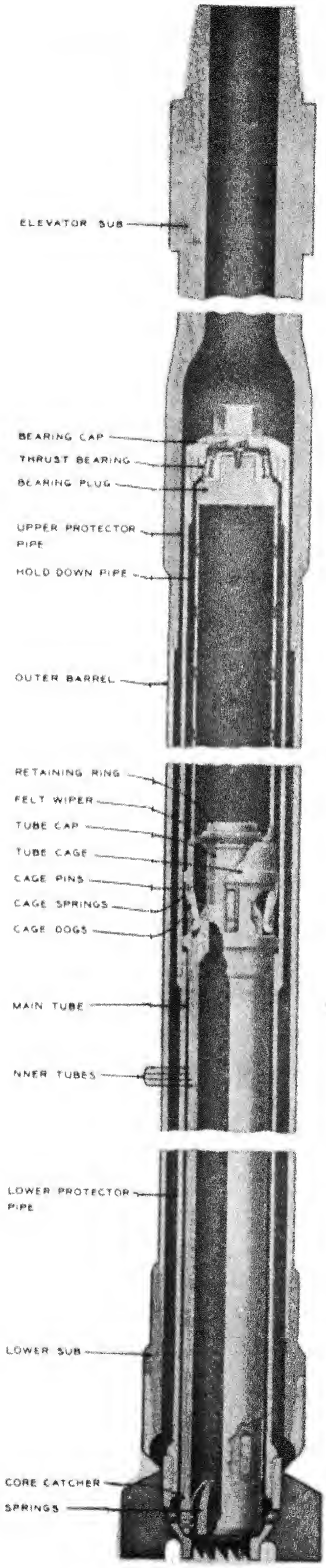
14.3 Wire-line or Retractable Core Barrels

Each time a core is taken with a regular rotary core barrel, the entire drill pipe must be inserted and withdrawn, and this operation is very time-consuming when the boring is deep In contrast thereto, a wire-line or retractable core barrel, Fig 289 and 290, is inserted and withdrawn through the drill pipe, and the latter remains in the bore hole until the bit is to be exchanged

Usually a wire-line core barrel is not lowered on a wire line but allowed to drop freely through the drill pipe, filled with drilling fluid As soon as the barrel is inserted, the kelly of the rotary is connected to the drill pipe and the mud pump run at slow speed A slight rise in pump pressure indicates that the inserted barrel is seated in the bit and that a latch or "driving dog" at the top of the barrel has engaged a slot in the drill collar and locked the barrel in working position Upon completion of the coring, the kelly is disconnected and set aside, and an overshot assembly, Fig 291, is lowered on a wire line A latch in the overshot engages the spearhead of the inserted core barrel, a pull on the wire line and the spearhead releases the driving dog, and the core barrel can then be withdrawn A new core barrel is inserted, and the drilling and coring is resumed while the core is being removed from the retracted barrel If it is desired to advance the hole without coring, a barrel with a solid or center bit is inserted The main drilling and coring bit shown in Fig 289 and 290 is a bladed or drag bit, which is replaced with a roller bit for coring in hard formations, Fig 300A

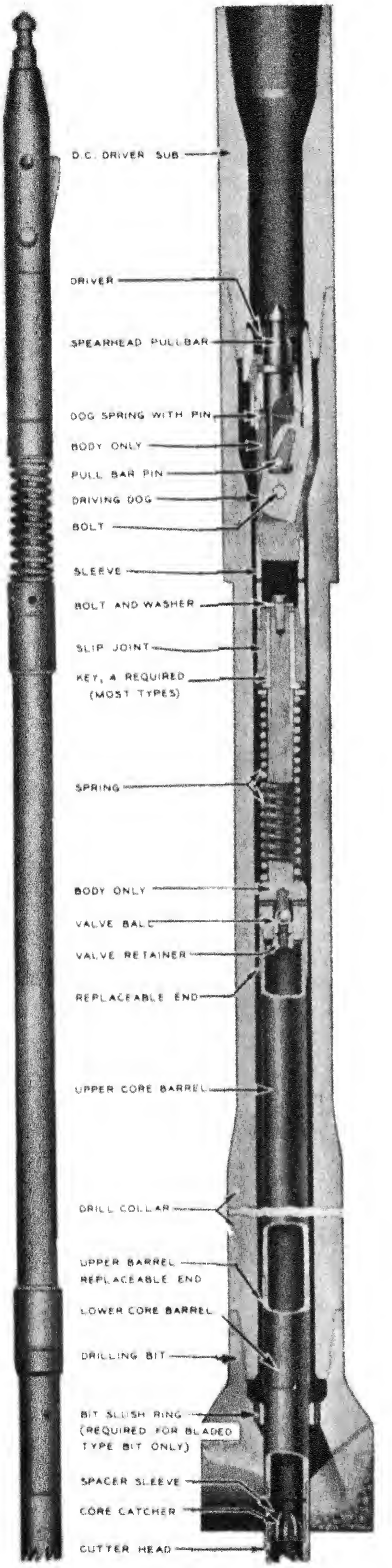
There are two main types of wire-line core barrels, one is called the Protruding Core Cutter type, Fig 289, because the retractable barrel protrudes slightly below the main bit and has a separate bit with hard-surfaced metal teeth The retractable barrel is rotated by the driving dog below the spearhead, and it therefore acts as a single tube core barrel A spring and a sliding joint between the spearhead and the barrel proper regulate the extension below the main bit and the feed pressure In hard formations the core barrel will be pushed back practically to the main bit with a corresponding increase in feed pressure In soft formations the core barrel bit will be pushed ahead of the main bit, but the extension is limited and loss of the barrel prevented by the collar above the bit

The second main type of wire-line core barrels is called the Seated in Head type, Fig 290, because the retractable barrel is seated on a small shoulder or seating head inside the main bit A swivel joint below the spearhead prevents the barrel from rotating with



JOHNSTON - SOLL CORE BARREL WITH TELESCOPING LINER

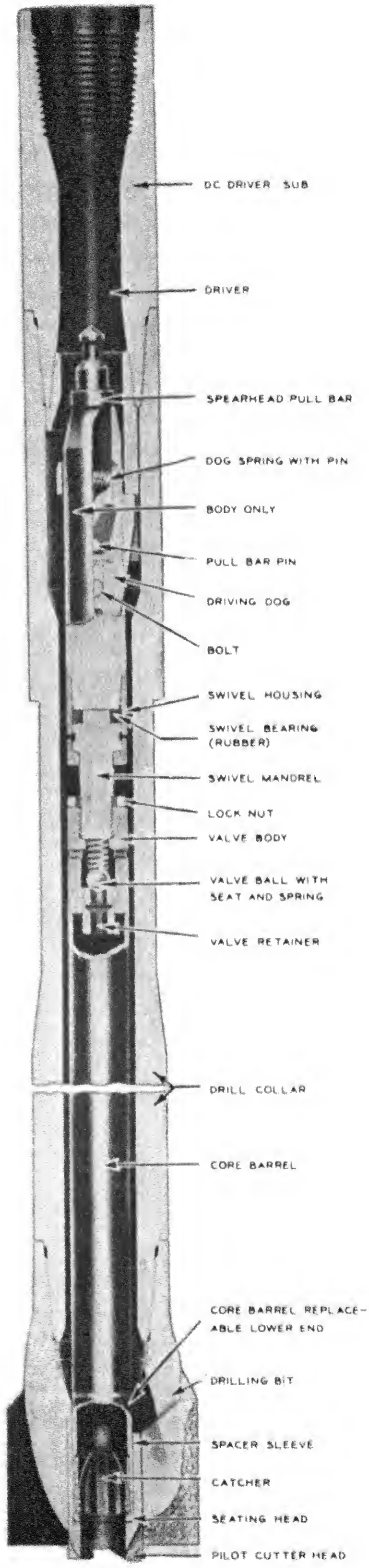
FIG. 288



REED ROLLER BIT CO

PROTRUDING WIRE LINE CORE BARREL

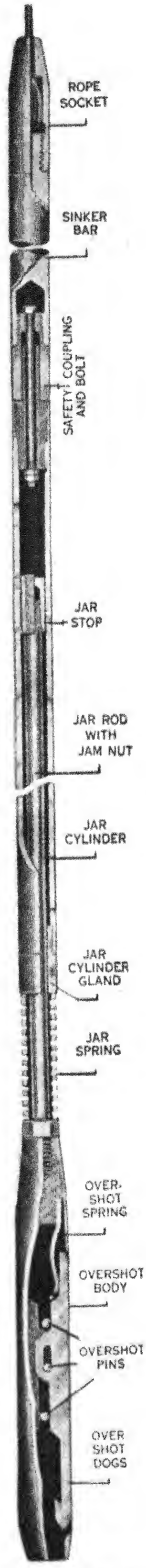
FIG. 289



REED ROLLER BIT CO.

SEATED WIRE LINE CORE BARREL

FIG. 290



BYRON JACKSON CO

OVERSHOT

FIG. 291

the drill collar and main bit, so that it acts as an inner tube in a double tube core barrel Opinions differ in regard to the relative merits of the protruding and seated types of wire-line core barrels, but several manufacturers furnish only the seated type A third type is similar to the seated type, but the latch in the spearhead is omitted, and the barrel is held in coring position by the pressure of the circulating drilling fluid When the retractable barrel is filled or blocked by the core, it is pushed upward and restricts the fluid passages with a consequent rise in pump pressure The barrel is then retrieved by means of a wire line and overshot or pumped out by reversing the flow of drilling fluid in the drill pipe and casing

The net internal length of wire-line core barrels varies from 6 to 11 ft depending on the diameter of the retractable barrel, and this diameter depends not only on the diameter of the main bit and the hole but also on the size of the drill pipe and the type and minimum internal diameter of the tool joints The increasing use of wire-line core barrels has therefore caused development of full hole and internal flush tool joints, Fig 174 and 175 Approximate corresponding diameters of the main bit, the drill pipe, and wire-line core barrels of the seated type are given in Table 12 The diameters of cores taken with the protruding bit type are slightly smaller

TABLE 12
PRINCIPAL DIAMETERS IN WIRE-LINE CORE BORING

Size of Bit Diam Hole Range in	Min Size Drill Pipe in	Min ID of Joint in	OD Barrel in	Diameter of Core in
5-3/8	3-1/2	1-3/4	1-11/16	1-1/4
8-1/2		2-1/4	2- 3/16	1-1/2
6-5/8	3-1/2*	2-1/2	2- 3/8	1-3/4
9-7/8	4-1/2	2-3/4	2-11/16	2- 0
7-7/8	4-1/2*	3-1/2	3- 5/16	2-1/2
up	5-9/16			

From catalogues by the Reed Roller Bit Co * Internal flush tool joints

The development of wire-line core barrels has greatly decreased the cost of taking cores in very deep bore holes and constitutes a significant advance in explorations for oil Coring with a wire-line core barrel causes so little delay that practically continuous cores often are taken of important formations Even when no cores are desired, a drilling bit for a wire-line core barrel, provided with a center bit, is often preferred to a regular rotary bit in controlled vertical or directional drilling, see Section 14 8, since the center bit can be withdrawn and a magnetic drift-direction indicator inserted and used without withdrawing the drill pipe, Fig. 300.

14.4 Pressure Core Barrels

In foundation explorations it is often difficult to obtain undisturbed samples of certain soils, due to release and expansion of gases dissolved in the pore water or entrapped in the pores of the soil Much greater difficulties of this type are encountered in deep explorations for oil The oil sands are often under enormous pressure and contain large amounts of gas besides oil and water The expansion of these gases, while the core is being brought to the ground surface and the pressure gradually reduced to atmospheric pressure, may not only force gas and oil out of the core but also change the porosity of the material Much more accurate estimates of the capacity of underground reservoirs of gas and oil could be made were it possible to preserve the cores under the original pressure until they arrive at the laboratory Two pressure core barrels, in which the core is sealed in the barrel before withdrawal, have been built and used with fair success in trial operations However, the development of pressure core barrels is still in the experimental stage

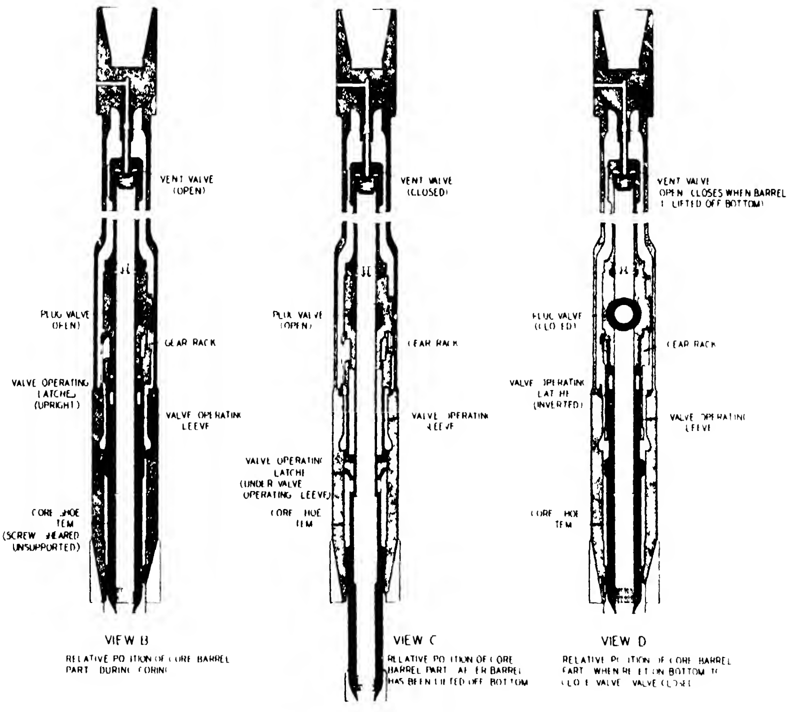


FIG 292 — A P I PRESSURE CORE BARREL

One pressure core barrel has been developed by the **U. S. Bureau of Mines** in cooperation with the **American Petroleum Institute** and is described by **Taliaferro and Heitdecker** (738) and known as the A P I pressure core barrel The core barrel is a double tube barrel with outside vent, the latter can be closed by means of a disk valve and the bottom of the inner tube with a spherical plug valve, Fig 292 The inner tube is provided with a long sliding shoe, which is held in position during lowering by means of small set screws These screws are sheared off when the

core barrel is seated on the bottom of the hole, and the inner tube is pushed slightly upward so that the disk valve below the outside vent is opened After completion of the coring, the entire assembly is lifted a few feet, View C, thereby causing the inner tube shoe to drop down until latches at the upper end of the shoe engage the lower end of another tube, which is connected to a gear rack operating the spherical plug valve The assembly is lowered again, View D, and the gear rack is thereby pushed upward and closes the spherical plug valve, whereupon the core barrel is ready for withdrawal During the first part of the withdrawal the entire inner tube assembly slides downward a little and closes the disk valve below the outside vent At the ground surface the inner tube with core and valves is shipped to the laboratory, where the pressure required to open the disk valve first is determined and the amount of released gases measured as the pressure is decreased to atmospheric pressure

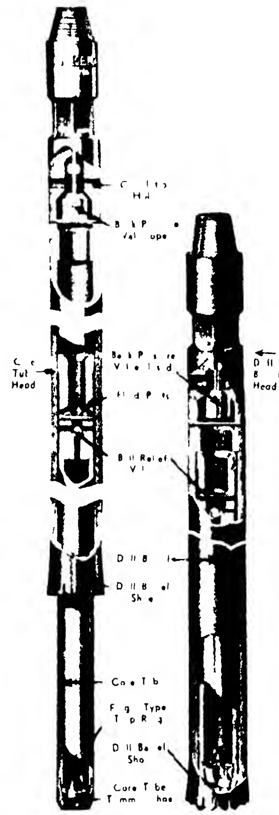
Another pressure core barrel has been designed by the **Carter Oil Co.** and described by **B. W. Sewell (732)** This core barrel has an intermediate tube, called the pressure tube, between the outer barrel and the inner tube The pressure tube can be closed with a disk valve at its upper end and a spherical plug valve at its lower end When the core barrel, after completion of the coring, is lifted off the bottom, the inner tube is pulled into the pressure tube and the valves are automatically closed The Carter pressure core barrel is somewhat more complicated in construction than the A P I pressure core barrel, but the valve closing mechanism is more positive in action and less susceptible to fouling by sand and cuttings, and it also has the advantage that nearly the entire core is preserved under pressure, whereas a 30-in long section of the core in the A P I pressure core barrel is below the spherical valve Cores about 1-1/2 in in diameter and 5 to 6 ft long have been obtained with these core barrels and a 6-1/4-in main bit The pressure in several of these cores was nearly equal to the hydrostatic pressure at the bottom of the bore hole filled with drilling fluid, but some difficulties with leakage have been experienced

14.5 Percussion Core Barrels

When deep bore holes are advanced by percussion or cable tool drilling, the sampling equipment must also be operated solely by cable Samples of soils can be obtained by attaching a tube or open drive sampler, also called a clay socket, to the drilling bit and driving it into the bottom of the bore hole, whereas a percussion or cable tool core barrel is used to obtain samples of rock Cable tool core barrels were developed nearly one hundred years ago and have been used extensively until the methods of rotary drilling and core boring were perfected and came into common use

A cable tool core barrel, designed and built by the **Baker Oil Tool Co. (101)**, is shown in Fig 293. It consists of an outer tube or drill barrel in which the inner tube or core barrel slides A shoulder at the top of the core tube prevents it from

dropping through the bit of the drill barrel The core tube has a ball check valve which permits outward but no inward flow of water, whereas the drill barrel is provided with a back pressure valve which permits inflow but no outflow of water In operation the core tube remains at the bottom while the drill stem with the drill barrel is raised and dropped repeatedly The rock around the core tube is thereby cut away and the tube forced down over the core Water flows into the upper part of the drill barrel during the upstroke, but the back pressure valve closes at the start of the downstroke, and the water is then forced down through ports in the head of the core tube, through the annular clearance between the two tubes, and out between the teeth of the drill barrel This automatic flushing keeps the teeth clean and removes the cuttings from the immediate vicinity of the core tube



CABLE TOOL CORE BARREL
FIG 293

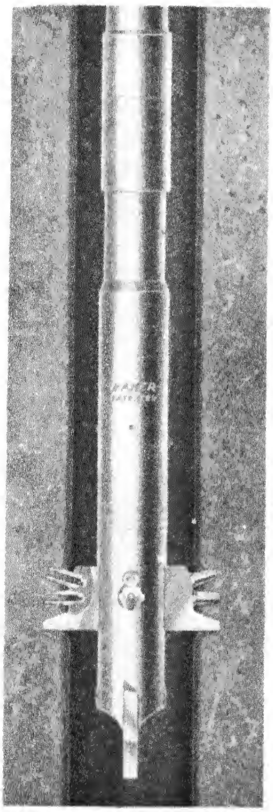
This core barrel is available with diameters of the drill barrel ranging from 3-9/16 to 7 in and the corresponding diameters of the core ranging from 1-5/8 to 3-13/16 in The chopping action of the drill barrel imposes greater stresses on the core than does diamond core boring, and the core is generally broken up into short sections, but over 90 percent recovery is often reported for 5-ft long cores The cable tool core barrel is primarily used in drilling for oil, but it has also been used to some extent in foundation and mining explorations

14.6 Side Wall Samplers

Samplers for taking small representative samples from the side walls of a bore hole are often used in explorations for oil When deep bore holes are advanced rapidly and without taking fairly continuous samples, relatively thin but important strata may be penetrated before the cuttings from such strata appear in the return flow of the drilling fluid and before the regular drilling bit can be exchanged with a core barrel When only a few cores have been taken during the advance of the boring, the entire hole is often surveyed by electrical logging after its completion Electrical logging is based on the same principles as the electrical methods of subsurface exploration, Section 2 3, and the results indicate only variations in the electrical properties of the materials in the walls of the hole Therefore, whenever the electrical log indicates strata of interest, it is desirable to obtain actual samples for positive identification and analysis of the material Such samples may be obtained with side wall samplers, of which three types are shown in Fig 294-296

The hydraulic side wall sampler, Fig 294, by the **Baker Oil Tools Inc. (183)** contains two small blades with sampling tubes which are folded into the main body

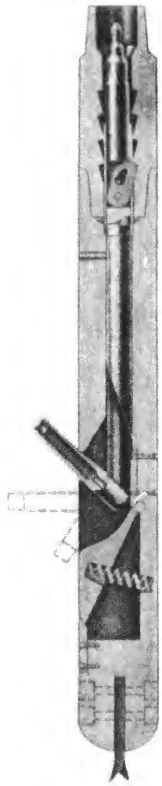
of the sampler during its lowering into the bore hole. On reaching the desired sampling depth, the circulation pump is started and hydrostatic pressure applied to a piston in the sampler body, which pushes the blades with the sampling tubes out until they are in contact with and penetrate slightly into the walls of the hole. The drill pipe with the sampler body is now lowered, and the weight will cause further rotation of the blades and force the sampling tubes into the formation. When the pump pressure is released and the drill pipe raised, the blades and sampling tubes again fold into the main body of the sampler and do not obstruct the withdrawal. The samples obtained range from 7/16 to 11/16 in. in diameter and from 1-1/4 to 2-1/2 in. in length. Four samples are obtained in one operation, but each operation requires lowering and withdrawal of the entire string of drill pipe.



BAKER OIL TOOLS INC.

HYDRAULIC SIDE WALL SAMPLER

FIG. 294



HOUSTON OIL FIELD MAT. CO.

WIRE LINE

SIDE WALL SAMPLER

FIG. 295

Some side wall samplers can be operated through the drill pipe as a wire-line core barrel. Such a sampler, developed by the **Houston Oil Field Material Co. (183)**, is shown in Fig. 295. The regular bit is replaced with a special bit and a drill collar with an opening and deflector for the side wall sampler. The sampler is connected through a hinge to a sinker bar with a trigger and a spearhead. This assembly may be lowered by means of a wire line or simply dropped through the drill pipe. During lowering the hinge is inactivated by a small shear pin, and fins and a special sleeve assure proper alignment in the drill collar. The deflector in the drill collar cushions the impact, but the shear pin is broken off and the sampler forced through the side opening in the collar and a short distance into the wall of the hole. The trigger locks the sinker bar to the drill collar, and when the latter is lowered a little, it will push the sampling tube further into the wall of the hole. A slight withdrawal of the drill collar and bit causes the sampler to return to a downward deflected position from which it can be withdrawn by means of a wire line and overshot. The samples range from 1 to 1-1/4 in. in diameter and 3 to 6 in. in length.

A side wall sampling assembly developed by the **Schlumberger Oil Well Surveying Corp. (183)** is lowered into and withdrawn from the bore hole by means of a wire line, and individual small sampling tubes are forced into the wall of the hole by explosives. The main body or housing of the sampler consists of elements with

SIDE WALL
SAMPLING GUN
FIG 296

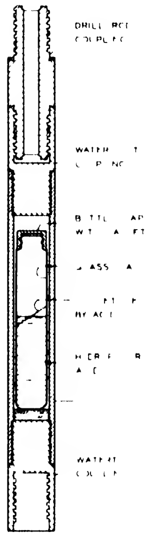
3 to 6 small gun barrels, Fig 296 Several elements may be combined so that up to 18 samples can be taken on a single round trip into the hole The small guns are fired individually by electrical ignition, and the sampling tubes form the bullets The tubes are open at the outer end and closed at rear end by a removable plug The powder charge is strong enough to force the entire tube into the wall of the hole As the tube is filled with material, the plug at the rear end is pushed out, and the material first encountered, generally contaminated by drilling fluid, is forced through and out of the rear end of the tube and discarded Wires connect the individual tubes to the corresponding gun barrels, thereby making it possible to recover the tubes and samples when the main sampler housing is withdrawn The samples range from 1/2 to 3/4 in in diameter and from 1-1/2 to 1-3/4 in in length

14.7 Surveying of Bore Holes

Borings may deviate from the original or planned course The boring operation itself often tends to cause the hole to assume the form of a long right-hand spiral instead of a straight line, but much more serious deviations may occur In general, the hole tends to turn parallel to the bedding planes of the formation when the angle between these planes and the axis of the hole is small and at right angle to the bedding planes when the original angle is large Deviations may also be caused by obstructions, improper operation, and by defective drilling equipment Once a hole starts to deflect, it tends to deviate further in the same direction, and the danger of deviation is therefore greater for inclined than for vertical holes

Deviation of the bore hole seldom presents a serious problem when the hole is only a few hundred feet deep, but it is often desirable to check the course of even relatively shallow borings, and it is generally necessary to determine the inclination and true direction of deep borings When modern methods of controlled vertical and directional drilling are used, Section 14 8, the inclination and direction of the hole is often checked for every 50- to 100-ft advance in depth The inclination is determined by means of an inclinometer or drift indicator and the direction by a compass or direction indicator The two instruments may be combined in a single drift-direction indicator Most of these instruments are used primarily in deep explorations for oil, but some of the smaller and simpler ones are also used to a considerable extent in mining explorations The latter instruments may possibly be used to advantage in surveying some deep borings for civil engineering purposes, for example in explorations for tunnels and in tracing fault zones in foundations for large dams

Acid bottle inclinometer.- The oldest and simplest instrument for determining the inclination or drift of a bore hole is the acid bottle inclinometer, also called the etch tube A glass tube, about 1 in in diameter and 4 to 5 in long, is half filled with hydrofluoric acid and placed in a watertight housing, Fig 297, which is attached to the drill rod or lowered into the bore hole on a wire line The joints of the housing must be tight to prevent the glass tube being crushed by the fluid pressure in deep holes The instrument must remain at the desired depth for a period sufficient for the acid to etch a distinct line on the glass The plan of this line or ellipse is the horizontal surface of the acid, and the latter must be diluted so that etching during the time required for lowering and withdrawal does not obscure the desired record For depths less than 500 ft a dilution of 1 part acid to 2 parts water may be used and a rest period of about 15 minutes for actual recording will generally be sufficient, whereas in holes more than 3000 ft deep it may be necessary to use a dilution of 1 part acid to 7 parts water and a rest period of 2 to 3 hours The tube is emptied of acid and rinsed immediately after withdrawal

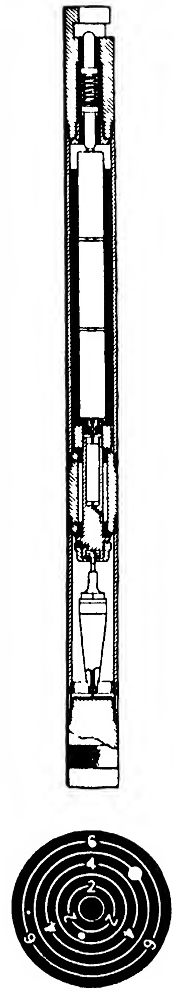


ACID OR ETCH TUBE
FIG 297

The angle of inclination of the etched ellipse is measured with a protractor or special goniometer Because of the influence of capillary forces, the measured angle is slightly larger than the actual angle of inclination of the tube during etching The correction is zero for vertical and horizontal positions of the tube and a maximum for an inclination of 45 degrees For this inclination and a tube with an inside diameter of about 1 in , the correction amounts to about 9°; that is, the angle of inclination of the etched ellipse will be 54° instead of 45° The correction depends not only on the inclination and diameter of the tube but also on the dilution of the acid

Other liquid level inclinometers.- The advantages of the acid bottle inclinometer are its simplicity and compactness, but the etching of the glass tube may require considerable time Two other inclinometers using the liquid level principle but with shorter recording time have been developed The Kiruna method, developed and used successfully in Sweden, utilizes a solution of copper salts from which the copper by electrical means is deposited on the inside of the tube and leaves a distinct mark of the surface of the solution The Syfo-Clinograph by the **Sperry-Sun Well Surveying Co.** (173) contains several compartments, the upper one of which is filled with a liquid dye The dye drips slowly into a second compartment from which, after a given period and after the instrument comes to rest, it is syphoned into a record chamber containing a folded paper chart After the dye has reached a maximum level in this chamber, another syphon tube transmits the liquid to the bottom compartment The chart when unfolded shows the paper stained to a sinuous curve, and the vertical distance between the highest and lowest points on this curve indicates the inclination of the tube

Mechanical inclinometers or drift indicators.- Greater speed of operation is obtained by recently developed instruments in which the inclination is indicated by the position of a plumb bob or a small ball rolling on the inside of a semispherical surface The position of the plumb bob or ball may be photographed on a record disk, Fig 300, a tripping mechanism may push a stylus in the plumb bob against the disk, or the disk may be pushed up against a sharp pointed plumb bob Instruments using these means of recording require a timing mechanism or an electrical control wire to the ground surface and make only a single record on a disk The Electro-Chemical Inclinometer, developed by the **Sperry-Sun Well Surveying Co. (173)**, requires no timing mechanism and permits several observations to be recorded on a single disk The instrument has a small universally mounted plumb bob with a floating platinum pin which is in continuous contact with the coated surface of the record disk, Fig 298 A small electric current passes from batteries through the plumb bob and pin to the disk and produces a change in color of the coating when the plumb bob is allowed to remain in a given position for a minute or more The distance from the dot thus produced to the center of the disk is a measure of the inclination. The size of the dots increases with increasing length of the rest period, and by varying the length of this period and thereby the size of the dots, it becomes possible to identify the various dots with the depths at which the observations were made

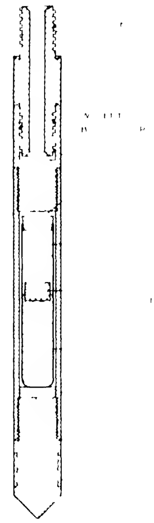


ELECTRO-CHEMICAL INCLINOMETER
FIG 298

These drift indicators are always placed in a protective casing or housing and are cushioned by spring shock absorbers They may be attached to the drill pipe, lowered into an open hole or through the drill pipe on a wire line, or they may be dropped through the drill pipe and recovered by means of a wire line and overshot They are built in various sizes with the diameters of the protective casing ranging from 1-5/16 to 2 in and the corresponding diameters of the record disk from 3/4 to 1-1/8 in The protective casing with sinker bars has a length of 6 to 8 ft.

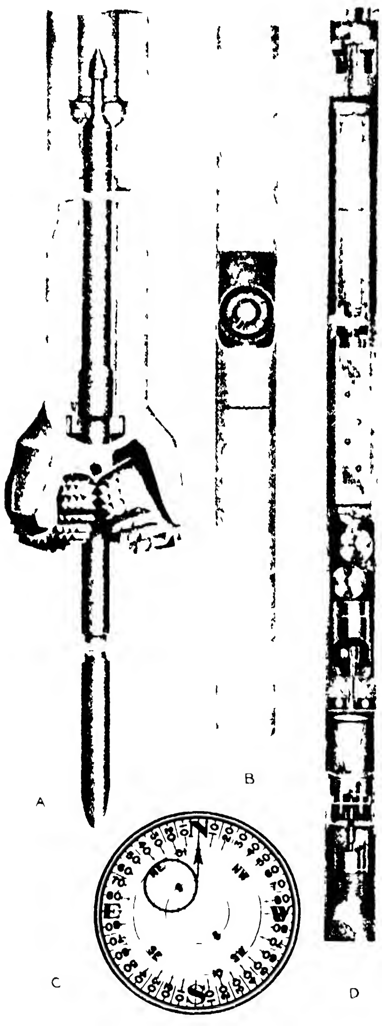
Maas compass.- The direction of the inclination or drift of a bore hole may be determined by means of a Maas compass, Fig 299, which is a companion instrument to the acid bottle inclinometer. A compass needle is mounted on a cork disk floating on melted gelatin in a glass tube. This tube is placed in a housing of non-magnetic metal and is attached to the inclinometer housing and oriented with respect to a vertical line on the acid bottle The acid bottle and the compass tube may also be placed in the same housing, and occasionally only a single glass tube is used, in which case the acid and the gelatin are separated by a rubber stopper. The instrument is allowed to remain at the desired depth of observation until the melted gelatin congeals, and the cork disk with the compass needle will thereby be held in the Magnetic North-South position.

Insulation may be placed around the compass tube, or the tube may be formed as a small vacuum bottle to prevent the gelatin from congealing before the compass reaches the bottom of a deep hole Agar-agar is added to the gelatin to raise the melting point when high temperatures are encountered in the bore hole The major axis of the ellipse etched on the acid bottle indicates the direction of the inclined hole, and the angle between this axis and a vertical plane through the compass needle is the deviation from Magnetic North



MAAS COMPASS
FIG 299

Drift-direction indicators.- The Maas compass is still widely used in diamond core drill holes of small diameter, but modern, combined drift-direction indicators are generally preferred for surveying deep borings, particularly oil wells of medium and large diameter Most of these instruments have a floating compass and a cross-hair plumb bob and are built to take a single record or up to several hundred records on one round trip into the bore hole In a single shot instrument the position of the cross hair is photographed directly on the record disk or compass chart, Fig 300, but in multiple shot instruments the position of both the cross hair and the compass chart is photographed on 16- or 35-mm film The exposure, and the winding of the film in multiple shot instruments, may be performed automatically by a timing mechanism or may be controlled from the ground surface by electrical means

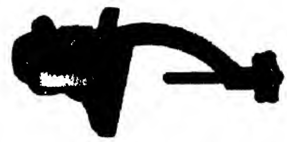


DRIFT DIRECTION INDICATOR
FIG 300

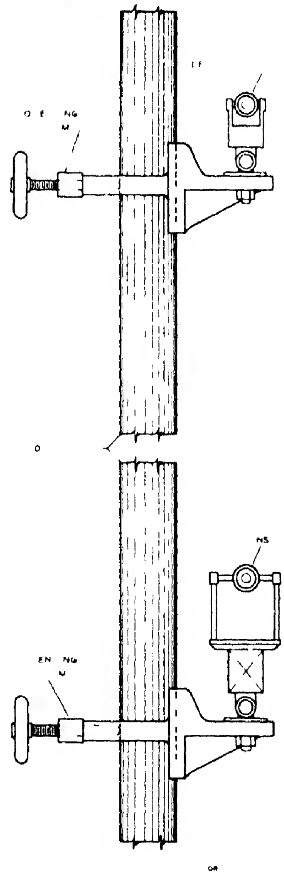
The indicator unit is placed in a non-magnetic housing with a length of 7 to 17 ft and an outside diameter of 2 to 2-1/8 in for small units and 3 to 4-1/4 in for regular units The corresponding diameters of a single shot disk range from 1-1/8 to 1-5/8 in The instrument may be attached to the drill pipe but is generally lowered into the bore hole or through the drill pipe by a wire line, or it is dropped through the drill pipe as a go-devil and recovered with a wire line and overshot When a wire-line coring bit is used, the bit must be withdrawn a short distance so that the compass will be at least 4 ft below the bit A magnetic direction indicator can also be used with a regular drilling bit and within the drill collar when the latter is made of non-magnetic metal

An indicator with a gyroscopic compass, developed by the **Sperry-Sun Well Surveying Co.** (173), is used for surveying cased borings or in the vicinity of magnetic formations, but the instrument has a diameter of 5-1/4 in and cannot be lowered through the drill pipe Drift-direction indicators with gymbal supported compass and diameters small enough to permit their use with standard diamond core drill rods have recently been developed, see **Townsend and King** (765), **Trotter** (766).

Orientation of drill pipe.- The direction of the inclination of the boring may also be determined by orienting the drift indicator with respect to adjoining and subsequent sections of the drill pipe and then maintaining the original orientation or measuring the angle of rotation of the pipes as they are lowered into the bore hole The orientation is made with a pair of orienting clamps, which may consist of a sighting bar or a section of angle iron with a sighting slot attached to an ordinary clamp, **Dahners and Cohen** (314), but specially designed orienting clamps facilitate the work and increase the accuracy of the results obtained



ORIENTING CLAMP



ORIENTATION OF DRILL PIPE

FIG 301

The orienting clamp shown in Fig 301, manufactured by the **Eastman Oil Well Survey Corp.** (118), has a small rotating table with adjustment screws and a taper socket to which a sighting bar or a transit can be attached A clamp is first attached to the indicator housing and oriented with respect to the indicator proper Another clamp is attached near the top of the adjoining section of drill pipe and aligned with a sighting bar inserted in the first clamp For accurate work a small transit, called a derrick transit, is used to align the clamps The sighting bar or a floor transit attached to the first clamp is sighted on a target or distant point, which thereafter serves as a reference point The first clamp is now removed and the drill pipe lowered until the second clamp is near the floor A second section of drill pipe is added and a clamp attached near its upper end and aligned with the target or with a sighting bar inserted in the floor clamp This operation is repeated each time a section of drill pipe is added

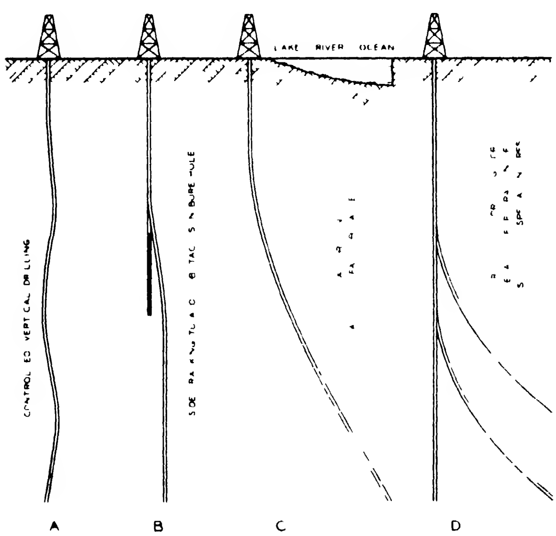
Upon reaching the bottom of the bore hole or the desired depth of observation, the drill pipe is rotated until the floor clamp is in line with the reference point or the total angle of rotation is determined by means of the floor transit The latter method is preferable since rotation of the drill pipe, because of friction between the pipe and the wall of the hole or the casing, may induce unknown torsional stresses and strains in the pipe with a consequent uncertainty or error in determination of

the orientation of the drift indicator. Rotation of the drill pipe against the direction in which it tends to turn is especially to be avoided. When the drill pipe must be rotated, it should be moved up and down a few times to relieve the torsion. The danger of errors from torsion is particularly great when the hole is crooked or has a large angle of inclination, and a survey by oriented drill rods may in such cases be unreliable. By use of a multiple shot drift indicator and by observing the angle of rotation each time a section of drill pipe is added, it is possible to make a complete survey of a hole in a single round trip.

Evaluation of survey data.- Evaluation of survey data, whether obtained by means of drift-direction indicators or by inclinometers and orientation of the drill rods, requires extensive use of spherical trigonometry, but computations can be facilitated by use of special tables and diagrams published by manufacturers of well surveying equipment When a Maas compass or a magnetic direction indicator is used, corrections should be made for the influence of the magnetic field produced by the drill pipe and casing The results of a complete survey are generally plotted in one horizontal and one or two vertical projections

14.8 Controlled Vertical and Directional Drilling

Complementary to the surveying of bore holes is the development of methods and equipment for bringing a deflected hole back on its original course or for producing a desired change in inclination and/or direction. The use of methods to maintain the course of a vertical hole is called controlled vertical drilling, Fig 302A, and deflection of the hole to reach a specified point outside the original vertical course is called controlled directional drilling. Methods and equipment for controlled deflection of a bore hole have been perfected during the last two decades to such an extent that these methods now are used for a great variety of purposes, such as for sidetracking of lost tools, cement plugs, bad faults, and other obstructions in the bore hole, Fig 302B, for drilling under buildings, rivers, lakes, ocean shores, and other surface obstructions without the inconvenience of starting with and operating through an inclined bore hole, Fig 302C; for detailed exploration of strata of special interest, lenses, veins, fault planes, or reaching oil or mineral producing deposits without drilling additional holes through the overburden, Fig. 302D; and for drilling multiple wells radiating from a single platform or artificial island in open water.



CONTROLLED VERTICAL AND DIRECTIONAL DRILLING

FIG 302

Controlled vertical drilling.- When the deviation of a vertical hole is small, it can usually be brought back to vertical direction by decreasing the pressure on the bit The bit and the heavy drill collar will then act as a pendulum suspended by the relatively slender drill pipe, and the bit will bear against and tend to cut more on the low than on the high side of the hole This tendency can be increased by use of a sharp and full gage bit with extended gage cutters and by increasing the speed of rotation The rate of change can also be controlled to some extent by the length of the drill collar and by placing a full gage reamer at the upper end of the collar. This reamer will act as a fulcrum and cause the lower end of the drill collar and the bit to bear against the low side of the inclined hole When the angle of inclination becomes large and a more abrupt change is desired, it may be necessary to use special deflecting tools. To prevent the angle of inclination from becoming too large, it is checked at frequent intervals by means of a single shot drift indicator When the hole is brought back to its vertical course, normal weight on the bit and speed of rotation can again be used

Controlled directional drilling.- A certain amount of control of the direction and inclination of a bore hole can be exerted without use of special deflecting tools. Advantage may be taken of the natural tendency of the hole to form a long spiral, and when the course of the hole assumes the desired direction, the inclination may be decreased or increased as required. A decrease in inclination may be effected by the methods described in the foregoing paragraph, and the inclination may be increased by increasing the weight on the bit, causing the drill pipe to buckle slightly and force the top of the drill collar against the low side of the hole and the bit against the high side. A full gage reamer placed near the bottom of the drill collar will act as a fulcrum and cause the top of the drill collar to bear against the low side of the hole and the bit against the high side A bit with a convex face, digging a concave hole in the bottom, also tends to increase the inclination However, when the original course of the hole is vertical and straight and when a relatively abrupt change in inclination and/or direction is desired, a whipstock or a deflecting bit must be used

Whipstocks.- A whipstock is a hardened steel wedge with a top angle of 2 to 5 degrees, hollow ground on the inside to fit the drilling bit Many types of whipstocks are made, some are designed to be seated on the bottom of the bore hole or on a cement plug and to be withdrawn and used again, Fig. 303A, whereas others can be locked in position above the bottom of an open or cased hole and must be left in the hole, Fig 303B and C. The whipstock is generally fastened temporarily to the drill pipe by means of a shear bolt, and it may be faced in the desired direction by orienting the drill pipe as it is lowered into the hole or by means of a special bottom hole orientation indicator Use of the latter requires a non-magnetic substitute or section of pipe above the bit. Two small magnets are placed in this substitute, and the whipstock is oriented with respect to the axis of these magnets.

One type of orientation indicator is similar to a single shot drift-direction indicator. In recording position the compass disk is at the same elevation as the

magnets in the non-magnetic substitute, and the compass will then indicate the direction of the axis of the magnets, whereas the dot made by the drift indicator indicates the relative direction of the inclination of the hole When the direction of the hole has been determined by a preliminary survey, the required angle of rotation of the whipstock can be computed In another type of orientation indicator the inclination unit is replaced with a second compass, and the angle between Magnetic North and the axis of the above mentioned magnets or the face of the whipstock can be read directly on the record disk obtained

WHIPSTOCKS
FIG. 303

After being oriented by one of these methods, the whipstock is pressed into the bottom or locked to the walls of the hole or casing Application of additional weight breaks the shear bolt, and the drilling can then proceed The heavy drill collar is temporarily replaced with a couple of sections of relatively thin and flexible drill pipe When the deflection is to be started from a cased bore hole, a section of the casing may be milled out before the whipstock is seated, or a special milling bit is used which drills a "window" in the casing, Fig 303C

Other whipstocks, especially those used in diamond drill holes of small diameter, consist of several parts A bottom wedge is first seated in the hole and its direction determined by a single shot survey instrument The actual whipstock has a pilot wedge which can be rotated and fastened in such a position that the whipstock proper is faced in the desired direction when the pilot wedge is seated on the bottom wedge

Deflecting bits.- The two principal types of deflecting bits are the spudding bit and the knuckle joint The former is a shovel shaped bit which, after being oriented in the desired direction, is moved up and down like a percussion bit until a 3- to 4-ft deep deflected hole is made, whereupon it is replaced with a spiral bit for further drilling The spudding bit is used only in relatively soft formations

DEFLECTOR DRILL
FIG. 304

The knuckle joint, Fig 304, has a long pilot bit which is connected to the main bit by a universal joint The pilot bit can be set at an angle to the main bit and is oriented in the desired direction before drilling is started The orientation is performed by the same methods which are used in orienting a whipstock The knuckle joint is automatically straightened out when the universal joint and main bit enter the deflected pilot hole After the deflected hole is advanced about 20 ft, the knuckle joint bit is withdrawn, the direction of the hole is checked by a survey instrument,

and normal drilling is resumed Some knuckle joint bits are self-orienting, that is, the universal joint is so constructed that the pilot bit is released and automatically points to the low side of the hole after the bit is pressed lightly against the bottom The bit is then locked in this position by lifting and resetting it, and its orientation with respect to the direction of the hole is known without making a separate orientation survey

14.9 Orientation of Cores

The angle of inclination, or dip, of subsurface strata can easily be measured on a core with visible stratifications or bedding planes, but the strike is much more difficult to determine The strike is usually estimated by comparison of profiles obtained in adjacent borings, but this method is unreliable when the formations are irregular, and when the spacing of the borings is relatively large

The strike may be determined by means of samples obtained with a drive sampler, when the sampler and drill rods are oriented during lowering or withdrawal, or when the sampling tube is oriented by means of a survey instrument attached to the tube or lowered through the drill rod However, this method is not reliable when the sample is obtained with a rotating core barrel, since the inner tube, the sample, or parts of the sample may have been rotated during drilling or in separating the sample from the material in situ

Irrespective of the manner in which a soil sample or rock core is obtained, its orientation can in many cases be determined in the laboratory by means of the magnetic or polar core orientation method This method utilizes very sensitive instruments for determination of the North-South axis of extremely small amounts of remanent magnetism, **Lynton** (721, 722), **Heiland** (214). The true orientation of the core in its original position in the ground can then be determined, provided the direction and inclination of the hole are known, and that the magnetic declination in the bore hole and of the remanent magnetism is the same as the magnetic declination at the ground surface

Polar core orientation is relatively inexpensive and, according to the **Sperry-Sun Well Surveying Co.** (173), the method has been used successfully for 60 to 70 percent of the cores submitted for tests Cores of some rocks -- such as limestone, dolomite, and anhydrite -- do not always contain sufficient remanent magnetism for a reliable determination of polarity, and the method cannot be used when there are strongly magnetic deposits in the vicinity of the bore hole unless the magnetic declination in the bore hole is determined The remanent magnetism may be influenced by geologic processes and even by stresses and strains produced during coring, **Heiland** (214, p.314-318). Changes in polarity may also be caused by placing the recovered core too close to a magnetic field or to an electric current Another possible source of error is that the grains of sedimentary deposits at the time of their formation may be oriented in accordance with the then existing magnetic field,

and that this orientation, on account of secular changes in the magnetic field, may not correspond to the current magnetic declination at the ground surface, **Johnson** **(142, 955).**

CHAPTER 15
SURFACE AND CONTROL SAMPLING

15.1 General

The special methods of sampling described in this chapter are those used in obtaining samples close to the natural ground surface or to the soil surface in open excavations and accessible explorations These methods are also used in taking control samples during construction of earth structures such as dams, levees, fills, and subgrades for roads and airports The general principles, advantages, and limitations of surface and control sampling methods are reviewed in Section 4 20 and their application in various types of soil is summarized in Table 8

By use of some of the surface and control sampling methods, especially advance trimming and block sampling, disturbance of the soil during the actual sampling operation can be reduced to a very small amount, and the major part of the disturbance of the sample often occurs before sampling, in particular when it is performed in deep accessible explorations The various causes of soil disturbance during advance of accessible explorations are discussed in Section 2 18, and the precautions which should be taken to eliminate or reduce such disturbances are summarized in the following paragraphs Some of these precautions should also be observed during preparations for sampling close to the natural ground surface or to the surface of earth structures

Sheeting, when required, should be placed in firm contact with the soil in order to avoid the start of soil movements behind the sheeting Such movements and failure of the soil are often progressive in character, increase the pressure on the sheeting, and may disturb the soil to be sampled

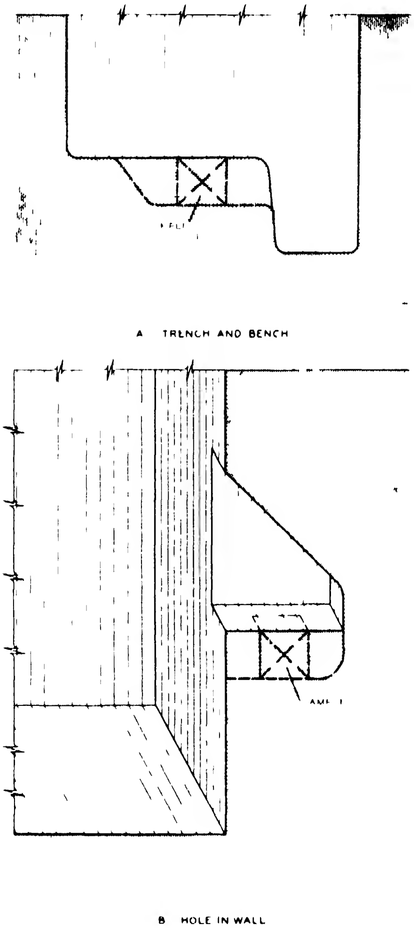
Insofar as possible, sheeting should be placed concurrently with advance of the exploration It should be realized that sheeting driven far ahead of the excavation may disturb the soil to be sampled by vibrations and displacement of soil

Dewatering by pumping directly from a sump or drainage ditches may be used in cohesive soils, but this method should be used only for a slight lowering of the ground-water level in cohesionless soils, and even then it is necessary to take special precautions to avoid failure or internal erosion of the soil to be sampled The ground-water level in cohesionless soils should be depressed below the bottom of the samples to be taken, so that the entire sample will be subjected to capillary pressures and acquire some apparent cohesion When the necessary ground-water lowering in cohesionless soils exceeds a few feet, it should be accomplished by means

of outside well points and not by pumping from an inside sump or drainage ditches

Stress changes in the vicinity of the bottom of a test pit, accessible boring, or the face of a tunnel are greater in both extent and magnitude than for a comparable boring of small diameter, filled with water or drilling fluid Except by use of compressed air, such stress changes cannot be reduced in accessible explorations, and they may cause failure, plastic deformations, and serious disturbance of the soil to be sampled Careful observations should be made to determine whether such plastic deformations occur, and they should be taken into consideration in choosing the locations of samples and in estimating their condition

The soil to be sampled should be protected against swelling, slaking, drying, and oxidation, which may be caused by seepage and rain water and by prolonged exposure to air and sun



PREPARATIONS FOR SAMPLING IN TEST PIT

FIG 305

The rough excavation, whether by hand or power tools, should be stopped not less than 6 to 12 in from the depth at which samples are to be taken, and the final excavation and trimming must be very carefully performed The distance from the samples to vertical sheeting, driven ahead of the excavation, should not be less than 12 in , and the samples should preferably be taken below the edge of the sheeting

Commonly used preparatory excavations for taking large samples in the bottom or side walls of a test pit are shown in Fig 305 In control sampling during construction of dams, levees, fills, and subgrades, the samples are generally taken below the last placed soil layer, which may be penetrated by an earth auger, or a shallow trench or pit may be excavated and a bench formed when large samples are to be obtained

The disturbances caused by stress changes and by exposure to water, air and sun are progressive in character and require time for full development Therefore, the samples should be taken as soon as possible after the rough advance of the exploration and immediately after the final excavation and trimming.

15.2 Representative Samples and Field Volume Determination

When a soil deposit is to be used as borrow material for construction purposes, partially disturbed but representative samples are generally adequate, although

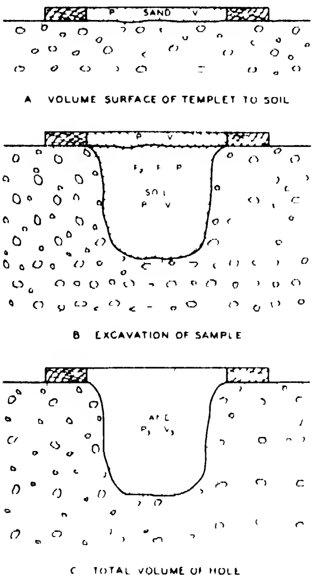
it often is desirable or necessary to determine the water content and unit weight of the soil in its undisturbed state Representative samples of individual strata are obtained by direct excavation or by means of an auger Composite representative samples of several strata are often required and may be obtained by preserving all the material obtained between the appropriate depths in an auger hole or from a channel of uniform cross section in the walls of a test pit, Fig 131 Large representative samples may be reduced to the desired size by quartering after thorough mixing A representative sample of an entire deposit is prepared by mixing samples from various auger borings and test pits in amounts proportioned in accordance with the thickness of the strata to be used and the spacing of the holes or pits

In control sampling during the construction of large earth structures and in exploration of surface or exposed deposits to be used as foundation for a structure, it is generally desirable to obtain undisturbed samples Even in surface sampling it is difficult or relatively expensive to take undisturbed samples of coarse, gravelly, and very dense soils, however, representative samples of such soils are often adequate provided the water content and density of the material in its undisturbed state is determined This may be accomplished by weighing the sample before any significant amount of water has evaporated and determining the weight or volume of calibrated sand, oil, or water required to fill the hole formed by excavating the sample

Volume determination by sand.- The sand used for field volume determinations should be dry, clean, uniform, and have a grain diameter between 0 5 and 2 0 mm The unit weight of the sand is determined for its loose state by pouring it slowly into a bucket or mold of known volume, which is weighed when full The drop of the sand during pouring, usually about 4 in , should be constant and the sand evenly distributed instead of forming a single cone Compliance with these requirements is facilitated by pouring the sand through a funnel The dry sand has a tendency to absorb moisture, and the consequent change in volume and unit weight and the error in determining the volume of the soil sample may be of considerable magnitude The calibrated sand should therefore be kept in a closed container, and it should preferably be dried and calibrated shortly before it is to be used for volume determinations

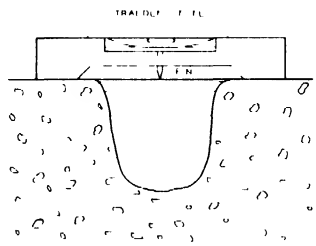
The field volume determination is facilitated and its accuracy increased by use of a templet with a circular hole, Fig 306 The ground is first leveled off and the templet placed upon it The hole in the templet is then filled with calibrated sand, the weight of which, P_1, is determined by the reduction in weight of the container from which the sand is taken The sand is then removed and the soil below excavated to a depth of 8 to 10 in and the combined weight, P_2, determined The hole is now filled with calibrated sand to the surface of the templet and the weight, P_3, again determined by the reduction in weight of the original supply of sand The weight of the excavated soil is then $P = P_2 - P_1$ and its volume $V = V_3 - V_1$, where V_1 and V_3 are the volumes corresponding to the weights, P_1 and P_3, of calibrated

sand. Care should be taken to pour the sand into the hole with the same drop and at the same rate which was used in the calibration The volume, V_1, may be assumed equal to the volume of the hole in the templet and the initial filling of this hole with sand may be omitted when the ground is very carefully leveled and it is desired to obtain a sample which is not mixed with calibrated sand



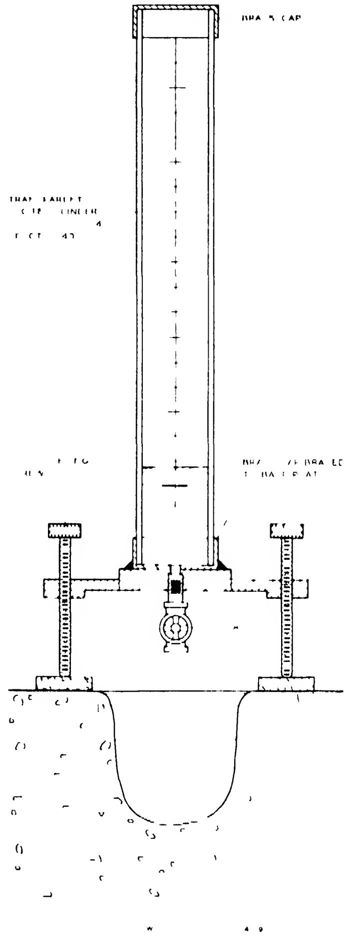
VOLUME DETERMINATION BY SAND

FIG 306



VOLUME DETERMINATION BY OIL

FIG 307



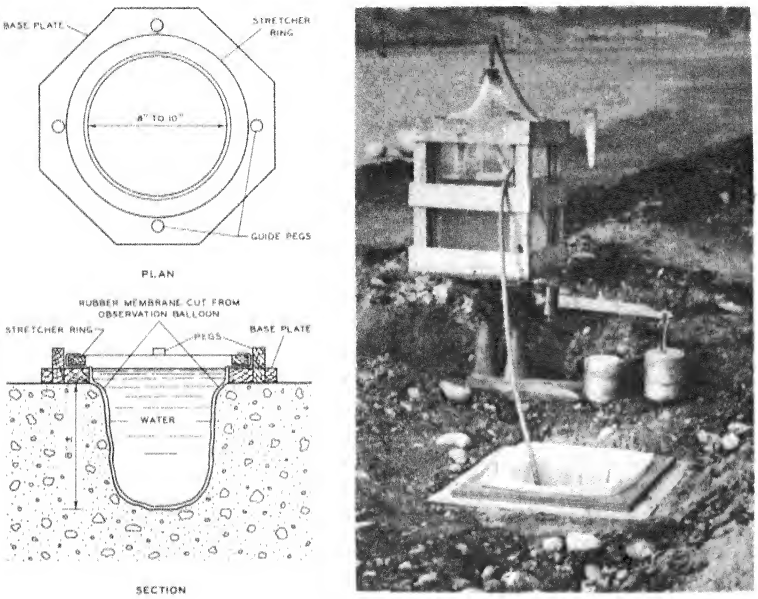
POE OIL PYCNOMETER

FIG 308

Volume determination by oil.- When the soil contains enough fine material to render it practically impervious to a heavy lubricating oil, the volume of the excavated hole may be determined conveniently by filling it with such an oil The ground should be very carefully leveled before the hole is excavated, and the correct level of the oil should preferably be determined by means of a straddle level with a point gage as shown in Fig. 307 When the specific gravity of the oil is known, the volume of the hole is determined by the weight of the oil required to fill the hole, but the volume may also be determined directly by means of the pycnometer shown in Fig 308 and suggested by **Poe (621).**

Volume determination by water.- Water is often used in determining the volume of the hole formed by excavating the sample, but the hole must then be lined with a rubber membrane A templet with a stretcher ring is often used to hold the rubber membrane in place, Fig 309, and the ground must be very carefully leveled before the templet is placed and the hole is excavated. After placing the rubber membrane and stretcher ring, the hole is filled with water to the top of the templet,

and the volume of the hole in the templet proper is later subtracted from the total volume to obtain the original volume of the sample The total volume may be determined by pouring the water from a graduated container or pycnometer or by weighing, Fig 309 When the soil does not contain too large pebbles and stones and a small sample and hole provide sufficient accuracy in determination of the unit weight,



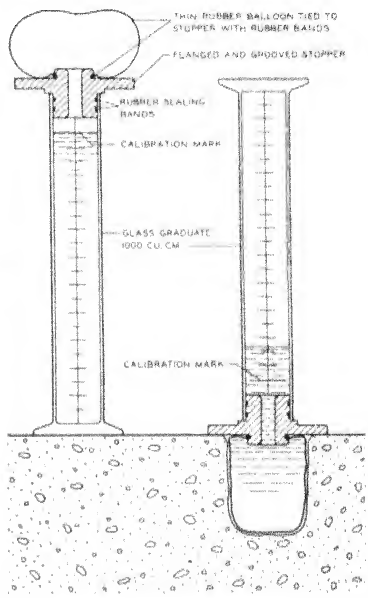


PHOTO BY BOSTON DISTRICT, CORPS OF ENGINEERS

VOLUME DETERMINATION BY WATER

FIG. 309

R. MC GUIN, ENG NEWS REC, VOL. 134, P. 70, 1945

MC GUIN WATER PYCNOMETER

FIG. 310

the rubber membrane or balloon may be attached to a transparent, graduated cylinder filled with water to a calibration mark, Fig 310 This assembly, suggested by **McGuin (616)**, forms a closed system which is calibrated by inverting the cylinder and placing the rubber balloon in a glass jar and with the flange of the stopper pressed against the top of the jar

General comments.- The unit weight of all except very soft soils may be determined by one of the above mentioned methods, but these methods are primarily used in coarse-grained soils with little or no cohesion, since the unit weight of other soils can be determined more conveniently by other methods However, field volume determinations may be used to check the accuracy or to estimate necessary corrections of results obtained by other methods Neglecting errors caused by careless work or by changes in the unit weight of calibrated sand due to absorption of moisture, the unit weights obtained by determination of the volume of the hole formed by excavating the sample may be slightly larger than the unit weight of the soil in situ, since the residual stresses in the soil surrounding the hole tend to decrease its volume In contrast thereto, the volume of samples obtained by the advance trimming, block or chunk sampling methods may be slightly larger than the original

volume and the unit weight of the sample consequently slightly smaller than that of the soil in situ

Representative samples are generally preserved in tightly woven canvas bags, Fig. 327, except when they are not weighed in the field and it is desired to determine the water content, in which case they are placed in tightly closed glass jars, Fig. 328, or metal containers

15.3 Open Drive Samplers for Surface Sampling

The open drive samplers described in Chapter 9 may also be used in sampling close to the ground or soil surface, but shorter and specially designed samplers are generally preferred, particularly in control sampling. Relatively short thin-wall samplers, similar to those shown in Fig. 180-182, have been used in control sampling when the samples are to be used not only for unit weight determinations but also for unconfined and/or triaxial compression tests, **van Auken (629).** The principal object of the majority of control sampling operations is to determine the water content and unit weight, and samplers with a length-diameter ratio of only 1 to 2 are generally used for this purpose. To facilitate determination of the unit weight, the sampling tubes have constant length, and the connections are so designed that the sample can be trimmed flush with the top and bottom of the tube. The samples will then have constant volume, and the samplers are often called constant volume samplers.

Design and operation.- The principal rules for design and operation of drive samplers used in deep bore holes, Sections 4.13 and 4 14, also apply to surface drive samplers. The wall thickness of the sampling tube should be reduced to the minimum required for structural strength, and the tube should have a sharp and well tapered cutting edge. When the tubes are very short, there is usually no inside clearance at the cutting edge, although it has been found advantageous to provide a small inside clearance, less than 1 percent, for sampling of some elastic and highly compacted soils The sampling tube should be pushed into the soil in a uniform and uninterrupted movement, without wiggling, preferably at a speed of not less than 0.5 ft per second. The tubes are pushed into the soft or loose soils by hand, but jacking by means of hydraulic or screw jacks or driving by a sledge or drop hammer is generally required to force the sampler into hard or very dense soils.

Conclusive systematic experiments to determine the influence of the diameter of the sampling tube on the porosity and unit weight of the sample have not yet been made; at least, the results of such experiments have not been published. A limited series of experiments was made by **Jáky (140)**, and the results indicated that the change in porosity is small when the diameter of the sampler is 45 mm or larger. As a consequence, the diameter of standard sampling tubes, used in control sampling for highway construction in Hungary, was changed from 100 to 50 mm. Short drive samplers used for control sampling in the U.S.A. have diameters ranging from 2 to

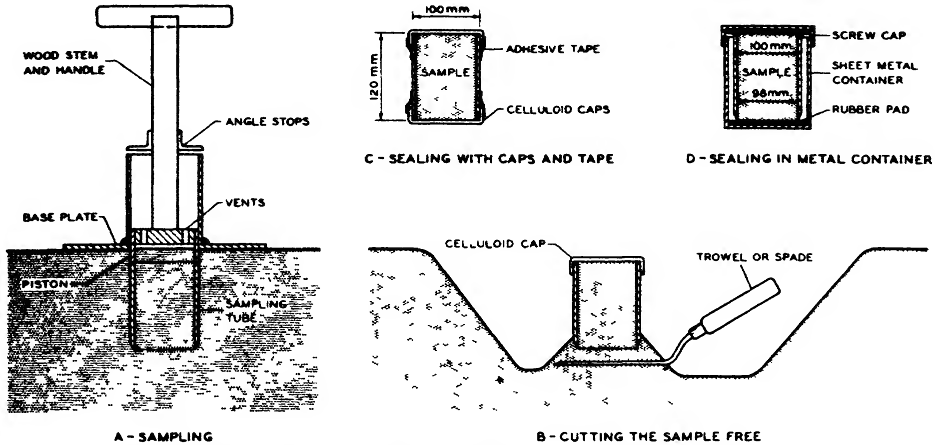
6 in. A few comparative tests with a 2-in. piston sampler, Fig. 317, and a 6-in. open sampler in uniform, fine sand have been made by the **Waterways Experiment Station,** Corps of Engineers. Compared with the 6-in. samples, the unit weight of the 2-in. samples was found to be about 1 percent smaller for dense sand and 1 to 3 percent larger for medium dense to loose sand In control sampling of clay, silt, and fine sand it is probable that satisfactory results can be obtained with 2-in. samplers, but a diameter of 3 to 4 in. is preferable for control sampling of coarser materials.

European samplers.- The surface drive sampler shown in Fig 311 has been used extensively in Germany, **W. Loos (229), L. Casagrande (506).** While the thin-wall sampling tube is being forced into the soil, it is often guided by an exterior tube with a foot plate, and wiggling or tilting of the sampler with consequent danger of disturbing the sample is thereby eliminated. The tube with the sample is recovered by digging and inserting a spade or trowel under the sampler The soil is trimmed flush with the top and bottom of the tube. When samples are to be sent to a laboratory, they are sealed by means of caps and adhesive tape, Fig. 311C, or by placing the tube and sample in a metal container with rubber pads at top and bottom, Fig. 311D.

It is difficult to remove samples of cohesionless soils from a sampling tube without disturbing the soil. The surface drive sampler shown in Fig 312, developed by **Szily (624),** has special top and bottom covers and tap holes in the sides so that permeability tests may be performed without removing the sample from the tube.

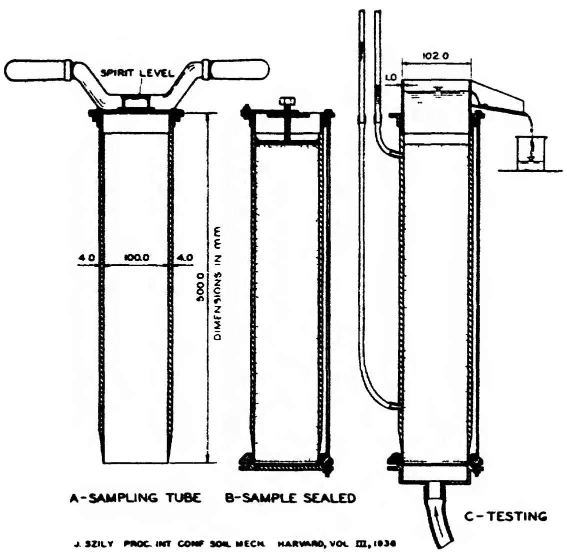
American samplers.- A surface drive sampler used for control sampling during construction of the Muskingum flood-control dams, **Knappen-Philippe (946),** is shown in Fig. 313. It consists of a section of 6-in tubing, the volume of which is 1/10 cu ft to facilitate computation of the unit weight of the sample. The tube is pushed into the soil by means of a drive ring with exterior guide lugs and a handle. A similar but smaller sampler, Fig. 315, has been designed by **Hansen and Foster** for the **Little Rock District,** Corps of Engineers The drive head is attached to a rod with a handle and provided with a built-in drop hammer for forcing the sampler into very dense or stiff soils. The hammer has an impact pad of canvas belting which reduces vibrations and wear of the drive head. The sampling tubes shown in Fig. 313 and 315 are left in the soil upon withdrawal of the drive head and handle, and they are recovered by digging and inserting a trowel, tiling spade, or a flattened crowbar under the tube. The tube may also be recovered by means of an Iwan type auger with the blade bent outward to permit its being pushed down over the sampling tube; see Fig. 133D.

In control sampling during construction of earth structures, samples are generally taken below the last placed soil layer or at depths of 6 to 24 in and occasionally up to 36 in. below the surface. Shallow borings are usually cleaned out and advanced between samples by means of earth augers. Except when the samples are taken very close to the soil surface, the recovery of the sampling tube by means



W LOOS PRAKTISCHE ANWENDUNG DER BAUGRUNDUNTERSUCHUNGEN SPRINGER BERLIN, 1937 — L CASAGRANDE DER STRASSENBAU VOL 25 P 68 1934

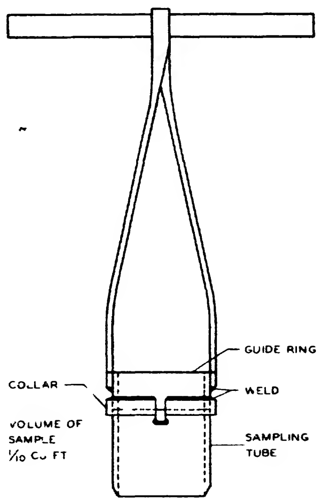
FIG 311 - GERMAN SURFACE SAMPLER



J. SZILY PROC. INT CONF SOIL MECH. HARVARD, VOL III, 1936

SZILY SURFACE SAMPLER AND PERMEAMETER

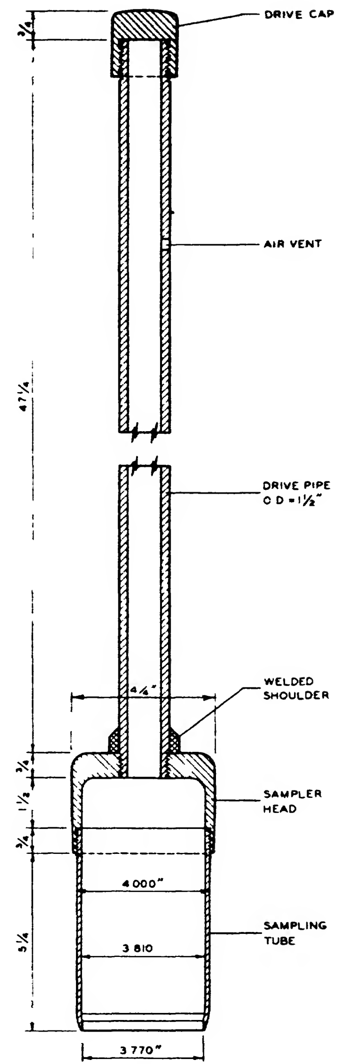
FIG 312



KNAPPEN-PHILIPPE ENG. NEWS REC MAY 7 1936

ZANESVILLE SAMPLER

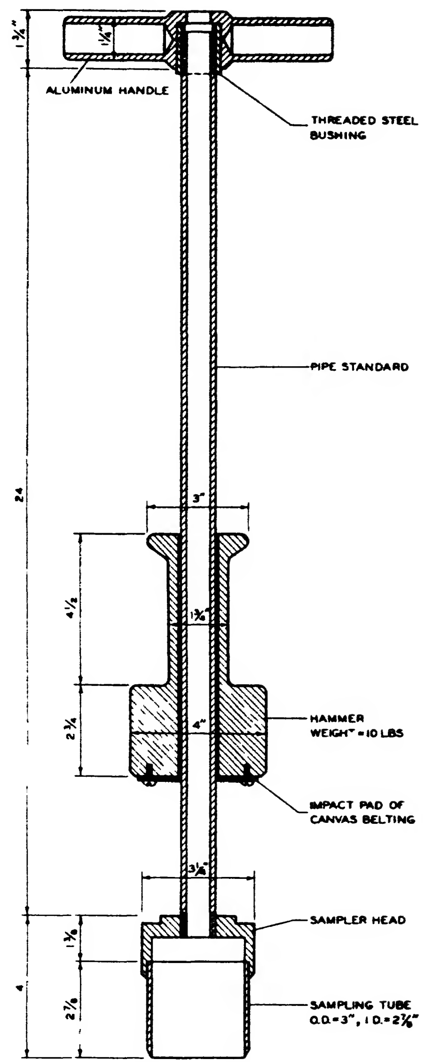
FIG 313



BY W. J. TURNBULL HASTINGS, NEB. 1936

TURNBULL CONTROL SAMPLER

FIG 314



BY R. HANSEN AND C.R. FOSTER LITTLE ROCK DISTRICT, CORPS OF ENG

LITTLE ROCK CONTROL SAMPLER

FIG 315

of digging is time-consuming, and considerable time can be saved by use of a control sampler, Fig 314, designed by **W. J. Turnbull.** The upper part of the short sampling tube is threaded and attached to a sampler head which is provided with a drive rod and cap The sampler is pushed into soft or loose soils by hand and driven into stiff and strongly compacted soils by blows of a sledge hammer until the top of the sample is about 1 in. above the top of the sampling tube proper. The drive rod is then moved back and forth to separate the sample from the subsoil and to provide an air channel to the bottom of the sample. After withdrawal the sample is trimmed flush with the top and bottom of the tube and then weighed. The bottom of the sample occasionally breaks off slightly above the cutting edge. The sample is then pushed down until it protrudes a little below the cutting edge, or the voids which remain after the preliminary trimming are packed with soil

The sampling tube is often provided with a small inside clearance at the cutting edge in order to decrease disturbance and especially compaction of the sample during the sampling The unit weight of the soil is generally computed on basis of the actual volume of the sample or tube and not on basis of the volume obtained by multiplying the height of the tube by the area enclosed by the cutting edge. This procedure is correct when actual compaction of the soil takes place, when the sample slumps after it enters the tube, and when excess soil displaced by the walls enters the tube. On the other hand, the volume represented by the area enclosed by the cutting edge should be used in unit weight computations when a significant expansion of the soil takes place during sampling.

Advantages and limitations.- The principal advantage of short open drive samplers is simplicity in construction and operation, and this advantage may be of great importance when thousands of control samples are to be taken during construction of a single, large earth structure However, it should be realized that minor changes in void ratio and unit weight of samples of cohesionless and/or partially saturated soils may take place during drive sampling. Such changes may be increased when the sampler is forced into the soil by hammering or slow, intermittent jacking, and further uncertainty in accurate determination of the unit weight is introduced when inside clearance is provided at the cutting edge of the sampler.

The increase or decrease in unit weight of the soil during drive sampling depends on the type, relative density, and degree of saturation of the soil, and on the dimensions and method of operation of the sampler In the absence of complete series of experiments in various types of soil, it can only be stated that the unit weight of loose to medium dense soils tends to be increased by a few percent during drive sampling whereas the unit weight of very dense soils may be decreased slightly. This tendency may cause the spread in unit weights of control samples to be smaller than that for the soil in situ

Satisfactory samples of fine-grained and saturated soils of soft to stiff consistency can be obtained by means of open, thin-wall drive samplers, although thin-wall samplers with a stationary piston are preferable for sampling of very soft or

loose soils. Undisturbed surface samples of stiff, brittle, or very dense soils, and of all coarse-grained soils should preferably be obtained by advance trimming and block sampling methods. However, control sampling of densely compacted soils by means of drive samplers may be justified in view of the simplicity of the method and the large number of samples to be taken, but it is advisable to check the accuracy of the results or to determine possible corrections by a series of comparative tests in each major type of soil used in the structure; that is, the unit weight of samples obtained with drive samplers should be compared with the results of both field volume determinations and the unit weight of samples obtained by advance trimming or block sampling methods

15.4 Piston Drive Samplers for Surface Sampling

Drive samplers with a free or stationary piston can often be used to advantage in surface and control sampling of clay, silt, and fine sand of soft to stiff or loose to medium dense consistency Thin-wall piston samplers of the types shown in Fig. 205, 207, and 224 may be used, but the clamping arrangements can be greatly simplified when the samples are taken close to the soil surface, and the piston can also be used to push short control samples out of the sampling tube The two piston samplers described below were designed by the writer for the purpose of taking short samples of constant diameter, length, and volume, which are to be used for unit weight determinations and other simple tests immediately after the samples are recovered.

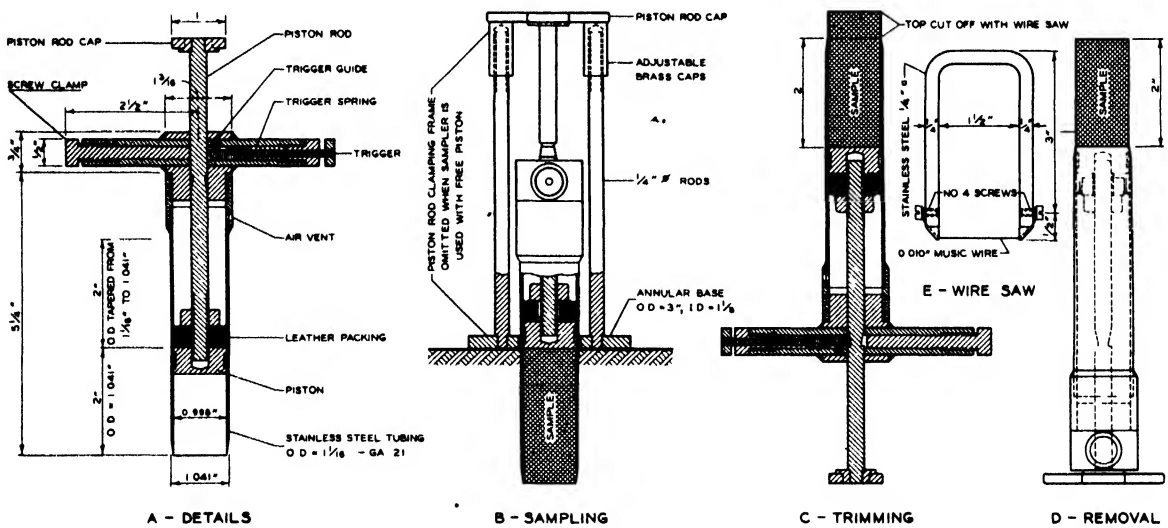


FIG 316 — 1" SURFACE PISTON SAMPLER

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Pocket-size piston sampler.- The piston sampler shown in Fig. 316 is small and light enough to be carried in a pocket or brief case and is designed for taking samples of 1-in diameter and 2-in. length during examination of soil deposits exposed in natural slopes, foundation excavations, and accessible explorations, and it

may also be used in either field or laboratory for taking small control samples or test specimens from large undisturbed samples

The sampler consists of a short section of thin-wall tubing with a sharp cutting edge and attached to a sampler head with handles containing a screw clamp and a trigger mechanism The piston is provided with airtight packing of very soft leather and is attached to a piston rod with a notch and a cap. When the trigger engages the notch in the piston rod, Fig 316C, the distance from the piston to the cutting edge should be equal to 2 in The length of the piston rod can be adjusted by loosening the lock nut and rotating the rod or piston Accurate adjustment is obtained by inserting an adjustment plug, exactly 2 in long, which also serves to verify that the cutting edge is plane and perpendicular to the axis of the tubing

To take a sample, a small area of the soil surface is first trimmed until plane by means of a wire saw and/or a glazier's knife The sampler with the piston in its lower position is then placed on the prepared surface, and a light pressure is exerted on the piston rod cap to assure full and even contact between the piston and the soil. If the sampler is to be operated with stationary piston, the piston rod cap is supported by an annular base plate with adjustable uprights, Fig 316B. In sampling of very soft and compressible soils, it is advisable to operate with stationary piston, but the piston rod support may be omitted in taking samples of firm and stiff soils

By pressing on the handles, the sampler is pushed into the soil until the notch in the piston rod is above the sampler head The movement should be uniform and perpendicular to the prepared soil surface The screw clamp in one of the handles is now tightened, thereby locking the piston rod and piston, and the sampler is then rotated and withdrawn. The sampler is turned over, the screw clamp released, and the sampling tube pushed down until the trigger engages the notch in the piston rod, Fig. 316C The protruding part of the sample is then cut off with a wire saw, the trigger is released, and the sample pushed out of the tubing and removed from the piston in a sidewise sliding movement

The sample is relatively short, and the total friction and adhesion between tubing and sample is not always sufficient to separate the sample from the subsoil and retain the sample. In such cases a knife should be pushed down along the sampler to provide an air passage and to cut the sample free In general, when a sample is to be used for unconfined compression tests, it is advisable to cut it free by means of a knife, since the lower part of the sample may be disturbed when separated from the soil in situ by a combined pull and rotation. Small samples or test specimens can be obtained from large samples by the above mentioned procedure, but the operation is often facilitated and the danger of disturbing the lower part of the sample is decreased by first cutting a slice from the large sample, about 2-1/2 in. thick, and pushing the piston sampler completely through this slice.

Since the samples have constant volume, the unit weight and degree of

saturation can easily be determined The constant cross-sectional area and length of the samples also facilitate performance of unconfined compression tests, for example by a compression apparatus similar to that shown in Fig 357.

Piston control samplers.- The 2-in piston sampler shown in Fig. 317, designed by the writer for and built by the **Waterways Experiment Station,** Corps of Engineers, is intended for general control sampling at the surface of earth structures or in shallow bore holes. A similar sampler with 3-in. diameter has also been built, and both samplers are provided with supplementary, long drive rods and

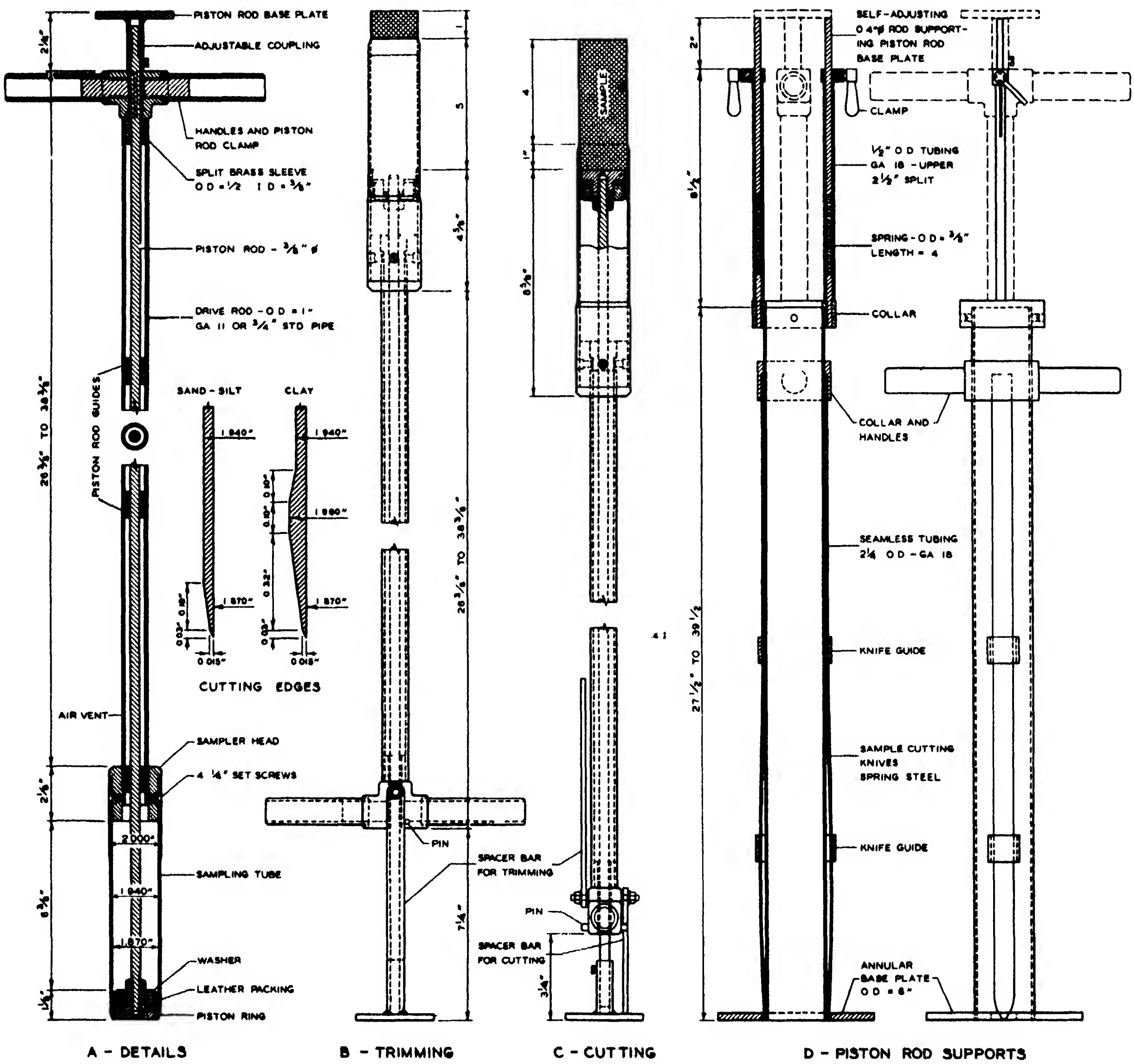


FIG. 317 — 2" PISTON SAMPLER FOR SURFACE AND CONTROL SAMPLING

piston rods so that they can be used to a depth of 6 ft below the ground surface. It is difficult and time-consuming to prepare a level and smooth surface at the bottom of a bore hole, and these samplers are therefore so designed that the partially

disturbed top and bottom sections of the samples can be cut off and discarded. So far the samplers have been used without any clearance at the cutting edge, but it is possible that a small inside and/or outside clearance may be advantageous in sampling of some soils.

In operation, the sampler with the piston flush with the cutting edge, Fig 317A, is seated on the bottom of the bore hole by exerting a light pressure on the piston rod base plate. The sampler is then pushed about 6 in. into the soil, whereupon the piston rod is clamped to the drive rod by turning one of the handles, and the sampler is rotated and withdrawn The handle is now turned until the clamp is released, and the sampler is then inverted By stepping or pushing on one of the handles, the sampling tube and drive rod are forced down until the long spacer bar, attached to the handle, abuts against the base plate of the piston rod, Fig 317B. The protruding part of the sample is cut off; the long spacer bar is pushed out, and the handle and sampling tube are pressed down until the short spacer bar touches the base plate of the piston rod The protruding 4-in long sample is then cut off, Fig. 317C, and the remaining soil in the tube is discarded When the sample consists of very soft or cohesionless soils, it may be more convenient to perform these operations with the sampler in horizontal instead of inverted vertical position. Shorter or longer samples can be obtained by use of spacer bars of various lengths.

The sampler should preferably be operated with stationary piston when samples are to be taken of soft, loose, and easily compressible soils, and samples of tough and/or sticky soils may not be retained in the tube unless they are cut free from the soil in situ In such cases the sampler should be operated within the guide tube shown in Fig 317D After the sampler and guide tube are seated on the bottom of the hole, the self-adjusting rods supporting the piston rod base plate are clamped to the uprights, and the sampler is pushed into the soil. The piston rod is then clamped to the drive rod by turning one of the handles, and the long cutting knives are pushed down and rotated, thereby cutting the sample free, providing an air channel to and supporting the bottom of the sample

It may be necessary to use jacking or hammering to force the sampler into stiff or dense soils, and a stirrup with a drive head and straddling the piston rod base plate is then placed over the handles of the drive rod. When jacking is required in a major part of the sampling operations, it may be more expedient to attach the drive rod directly to a quick acting hydraulic drive or to a rack and pinion jack, which in turn may be mounted on a light truck The jacking arrangement should be similar to the feed mechanism of a core drilling machine, so that the drive rod can be carried up through the jack and the piston rod can be clamped to a stationary bar or frame above the jack. It would thereby be possible to use the jacking arrangement both to force the sampler into the soil and to push the sample out of the sampling tube.

Advantages and limitations.- Compared to the short open drive samplers described in the foregoing section, the piston samplers shown in Fig. 316 and 317

have the advantage that the piston helps to retain the sample in the tube and also can be used to push the sample out of the tube. In practical sampling operations with the piston sampler shown in Fig 317 it was found that the time required for sampling is materially shorter than with the conventional open drive sampling tubes of constant volume, at least when the sampler is operated with free piston. In the latter case the weight of and friction acting on the piston and piston rod slightly increase the pressure on top of the sample and may cause a very small additional compaction of samples of loose soils. On the other hand, when the sampler is operated with stationary piston, the pressure on top of the sample is automatically regulated in such a manner that it tends to decrease disturbance of the soil structure, compaction, or expansion of the soil

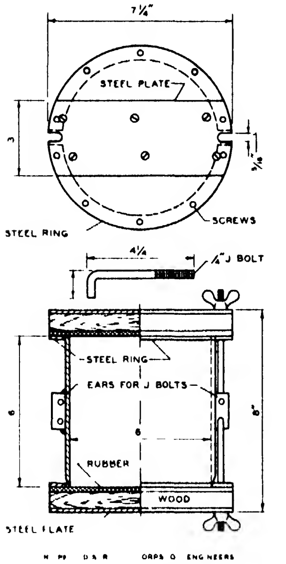
As in sampling with open drive samplers, sampling with piston samplers described in this section may cause a slight disturbance and decrease in strength of some soils, a small increase in density of loose soils, and a still smaller decrease in density of very dense soils The comments on page 376 concerning the fields of application of short open drive samplers and on checking the condition of the samples apply also to piston samplers

15.5 Sampling by Advance Trimming

The disturbance caused by displacement of soil during drive sampling can be eliminated to a large extent when the sample is trimmed approximately to the desired diameter for a short distance below the cutting edge of the sampling tube, Fig 134 The trimming and the advance of the sampling tube is performed alternately and in small steps, and the trimming should be as close as possible to the final size without cutting into the actual sample. The final trimming is made by the cutting edge of the sampling tube which should be advanced without wiggling or change in direction of movement A large open drive sampler, the liner of a drive sampler, or a suitable section of tubing with a sharp cutting edge or a shoe may be used. Since most of the soil displaced by the walls of the sampler is removed and not pushed aside, the wall thickness is only of minor importance.

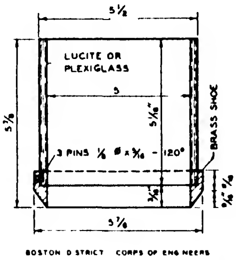
Advance trimming is primarily used in taking fairly large samples, 4 to 8 in. in diameter, for unit weight determinations in the field or for consolidation, shear, triaxial, and other laboratory tests. When samples are to be shipped to the laboratory, they are generally preserved and shipped in the sampling tube A cylinder with covers, designed for sampling by advance trimming by the **Fort Peck District**, Corps of Engineers (110), is shown in Fig 318 When the sample is to be used for unit weight determinations, it is especially important that there be no voids between the sample and the cylinder To facilitate detection of such voids, the **Boston District**, Corps of Engineers, **Shannon** (171), introduced a constant volume cylinder of transparent Lucite with a detachable brass shoe, Fig. 319. A slightly different design of such a sampling cylinder and appurtenances is shown in Fig. 320. The brass shoe is flush with the cylinder wall to permit easier and close advance trimming,

and the advance of the sample in a vertical direction without wiggling is facilitated by a detachable head frame with handles and a circular spirit level. The use of a cylinder of transparent Lucite or Plexiglas for both the actual sampling and preservation of the sample has the additional advantage that the sample later can be examined without removing it from the cylinder and that there is no danger of corrosion and chemical changes during shipment and storage.



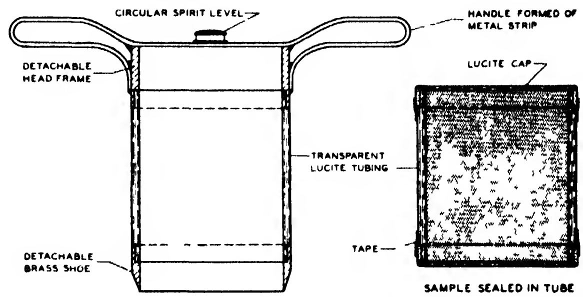
FORT PECK SAMPLING CYLINDER

FIG 318



CONSTANT VOLUME CYLINDER

FIG 319



PROPOSED CYLINDER FOR ADVANCE TRIMMING

FIG 320

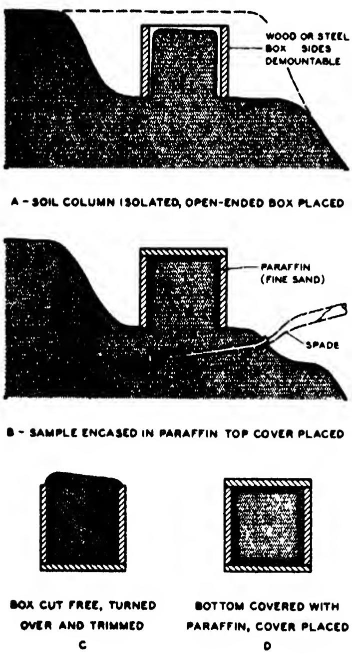
Sampling by the method of advance trimming is considerably slower than sampling with open or piston drive samplers, but the method will in many cases furnish less disturbed samples than drive sampling However, some disturbance or change in the physical properties of the soil may occur during the actual sampling by advance trimming, in addition to disturbances occurring before or after the actual sampling The sampling cylinders used in sampling by advance trimming are usually not provided with inside clearance at the cutting edge, and friction and adhesion between the sample and the cylinder may be of appreciable magnitude The soil immediately below the cutting edge is deprived of lateral support on account of the advance trimming; its bearing capacity is decreased, and it may be disturbed by the pressures transmitted to the soil column during advance of the sampling cylinder. Therefore, advance trimming may cause greater disturbance than drive sampling when the soil is very soft and sticky. The final trimming produced by pushing the sampling cylinder down over a column of very brittle, hard, or partially cemented soils, or soils containing pebbles and stones may cause local shear failures and parts of the sample to be torn out as in drive sampling. Less disturbed samples of such soils can usually be obtained by block sampling. The unit weight of samples obtained by advance trimming may be slightly smaller than that of the soil in situ on account of expansion of the soil upon elimination of residual lateral stresses.

15.6 Block Sampling

Undisturbed samples of very stiff or partially cemented soils may be obtained simply by cutting out a block or chunk of soil and preserving it by dipping or

encasing in paraffin. This method, also called chunk sampling, is often used for unit weight determinations. The sample with its paraffin cover is weighed and the total volume determined by the water displacement method or by the loss in weight during submergence. The paraffin cover is then removed and placed in a pan with water and boiled. The paraffin melts and floats to the surface of the water, whereas any soil adhering to the paraffin sinks to the bottom of the pan. After cooling the paraffin is skimmed off, weighed, and its volume computed, thereby making it possible to determine the weight and volume of the soil sample proper.

A method which is intermediate between advance trimming and block sampling consists in providing a cardboard or sheet metal cylinder, the latter split along a longitudinal seam, with a shoe having an internal diameter from 1/2 in. to 1 in. smaller than that of the cylinder. After trimming of the soil and advance of the cylinder, the annular space between the sample and the cylinder is filled with paraffin, and the sample is shipped to the laboratory with the paraffin cover protected by the cylinder. The seam in the sheet metal cylinder is opened and a cardboard cylinder is cut lengthwise prior to removal.



GILBOY BLOCK SAMPLING METHOD
FIG. 321

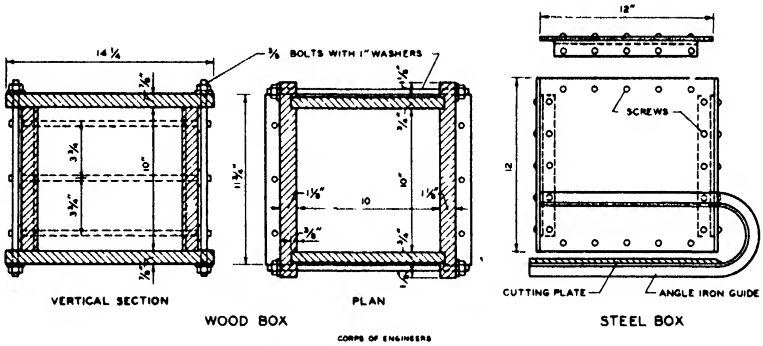


FIG 322 - BLOCK SAMPLING BOXES

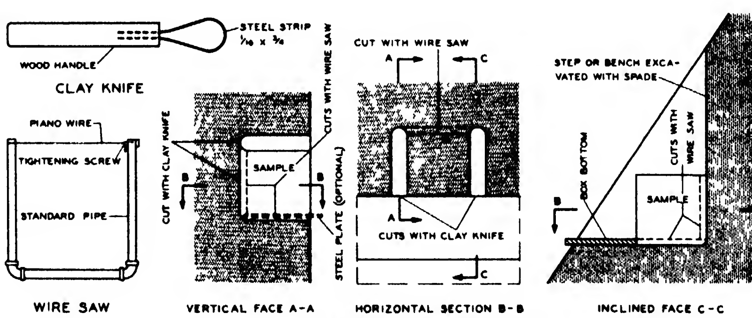


FIG 323 - BLOCK SAMPLING OF CLAY

Large, cubic block samples of soils with a relative small cohesion or strength may be obtained by means of a sampling procedure suggested by Gilboy (927) and shown in Fig. 321. A column of soil, 8 in. to 12 in. square, is first isolated and a box with the top and bottom covers removed is lowered over it. The space between the box and the soil is filled with paraffin, or with moist and carefully tamped sand when the soil is very coarse grained and only partially saturated. The top of the

sample is trimmed and covered with paraffin or sand, and the box cover is then attached. The sample is now cut free with a spade or flat steel plate and turned over, whereupon the bottom of the sample is trimmed, covered with paraffin or sand, and the bottom cover plate attached. Sheets of soft rubber are occasionally placed between the sample and the box instead of filling the space with tamped sand.

The Gilboy method can be used in any soil with some true or apparent cohesion, but a method devised by **Brandley and Wilson** and shown in Fig. 323 involves less work when block samples of fairly stiff clay are to be cut from a vertical or steeply inclined face in a test pit or foundation excavation. The work is greatly facilitated by use of a large wire saw and a clay knife, the latter being similar in principle to the power clay knives used in excavation of tunnels in clay. In a vertical face grooves with a width of about 3 in. are first cut on three sides of the sample by means of the clay knife, and the remaining two cuts are made with the wire saw. When the face is inclined, a bench is first excavated and two grooves then cut with the clay knife. The block is removed by hand, but a plate is pushed in under sample prior to removal if the soil adheres too strongly to the parent material in spite of the cut with the wire saw. The samples are cut oversize, trimmed to the desired dimensions with the wire saw, placed in a box, and encased in paraffin.

The sample is shipped to the laboratory in the box, and removal of the latter is facilitated when not only the top and bottom covers but also the sides of the box are easily dismantled. Examples of such boxes of wood and steel are shown in Fig. 322. A pair of angle irons, bent into U-shape, may be attached temporarily to the sides of the steel box and serve to guide a steel plate which is pushed in under the sample, **Hough** (125).

Excepting conditions which cause disturbance of the soil before the actual sampling, block or box sampling is the best available method for obtaining large undisturbed samples of soils which have sufficient true or apparent cohesion to be isolated in a soil column without undergoing excessive deformations. Box sampling is practically the only method by means of which undisturbed samples can be obtained of soils containing considerable amounts of gravel and stones. Isolation of the soil column and elimination of residual lateral stresses will cause expansion of the soil and a corresponding decrease in its unit weight. The expansion is usually very small or negligible, but it may be of considerable magnitude when the soil contains gases entrapped in its pores or dissolved in the pore water; see Section 5.9.

15.7 Surface Core Boring

A fully satisfactory and economical method for obtaining undisturbed samples and control samples of brittle, hard, or very dense soils in a dry or partially saturated condition has not yet been developed. Satisfactory samples may be obtained by advance trimming or block sampling methods, but these methods are relatively slow and expensive and the cost of the sampling increases rapidly with depth on

account of the necessity of excavating a pit or trench to the bottom of the samples. Relatively inexpensive samples can be obtained by means of open or piston drive samplers, but great pressure or hammering is required to force such samplers into the above mentioned soils, and the sampling operation will generally cause some disturbance of the sample.

The use of double tube core barrels of the types shown in Fig. 269-273 may be considered. However, water cannot be used as a circulating fluid since it would enter the partially saturated soil and change its water content. Even drilling fluid may cause excessive contamination of porous and partially saturated soils, and its use may also be inconvenient or objectionable in control sampling. A light-weight, portable drilling machine and a special core barrel, utilizing compressed air for cooling the bit and removing the cuttings, has recently been developed by the Civil Aeronautics Administration (553). The bit is set with medium-size diamonds and has openings for passage of compressed air. The core barrel is primarily designed for obtaining cores of various types of airfield pavement.

Another solution would be to remove the cuttings by means of a spiral auger on the outer barrel, or to combine the principle of the hand-operated auger core barrel shown in Fig. 135B with the best features of design of the core barrels shown in Fig. 269-273. The core barrel may be operated by a relatively light drilling machine, mounted on a truck and preferably provided with hand-controlled hydraulic feed or hand-operated rack feed, Fig. 129. It may be advantageous to use compressed air in combination with an auger type bit and outer barrel, since the air would help to remove the cuttings and tend to keep the bit cool, and the outlets could be placed at a safe distance above the bottom of the bit. Consideration should also be given to the use of a stationary piston in the inner tube. Such a piston would tend to decrease disturbance of the core and help to retain it, and it may also be used to push the core out of the inner tube. By addition of spacer bars or notches in the piston rod, as for the piston samplers shown in Fig. 316 and 317, it may even be possible to obtain a core of constant diameter and length without dismantling the core barrel or removing it from the drill rod and drilling machine.

CHAPTER 16
PRESERVATION AND HANDLING OF SAMPLES

16.1 General

This chapter deals with the preservation, marking, and shipment of samples, and their examination and general handling in the laboratory up to but not including the preparation of test specimens for physical tests

The first operation after withdrawal is partial dismantling of the sampler or core barrel, so that the gross length of the sample can be determined and the sample, with or without liners, can be removed from or sealed in the sampling tube. The dismantling should be performed without shocks and blows which may cause disturbance of the sample, especially when it consists of cohesionless soils.

When composite samplers or core barrels are used, the gross length should be determined before the shoe is disconnected and the liners or sample pushed out of the tube Open drive samplers or core barrels should be emptied of sludge before the gross length is measured. In case of piston samplers, any downward movement of the piston rod and piston upon release of the piston rod clamp should be measured accurately, since such a movement serves to determine the gross length when there is no water between the piston and the top of the sample. The gross length should be checked after the piston is removed; the presence of water over the top of the sample should be noted in the boring record, and the quantity of water should preferably be measured.

Careful determination of the gross length and recovery ratio of the sample is essential for judging the condition of the sample and for estimating the safe depth of penetration of the next sample to be taken The net length of the sample should be determined as soon as the sample has been trimmed for sealing, and other control measurements and tests should be performed as required; see Section 16.13.

Protection of the sample against changes in water content and chemical composition is one of the principal problems encountered after the sample is obtained. The efficiency of various methods of protecting or sealing the sample against evaporation of water was investigated by experiments extending from October 1942 to March 1946. The results of these experiments are summarized in Table 13 and are discussed below and in the sections dealing with the particular methods of sealing samples. The experiments were performed under laboratory conditions; the temperature of the paraffin was carefully controlled; the ends of the tubes were thoroughly cleaned before the sealing plugs were cast; and the disks and caps had a

TABLE 13 - EFFICIENCY OF VARIOUS METHODS OF SEALING SOIL SAMPLES AGAINST LOSS OF WATER

No.	METHOD OF SEALING / ELAPSED TIME IN DAYS →	1/2	1	2	4	7	12	19	32	47	130	226	324	539	1250
		Loss of Water in g from Samples with Approximate Wet Weight 370 g, Dry Weight 290 g, and Water 80 g													
1	Unprotected sample	12.5	24.1	44.1	67.2	74.2	75.6	76.7	78.2	78.2	78.5	76.7	75.4	78.6	78.8
2	Covered - one layer of wax paper	1.4	2.8	5.5	10.5	20.5	35.8	56.6	76.4	77.5	78.4	76.4	75.5	78.4	78.5
3	Wrapped - two layers of wax paper	0.9	1.7	3.6	8.1	15.4	25.6	42.5	68.7	75.7	77.3	75.4	74.5	77.2	77.3
4	Wrapped - two layers of Cellophane	0.2	0.5	1.0	1.7	2.4	3.7	5.6	8.9	13.9	48.9	75.2	75.4	78.5	78.6
5	Paraffin brush coats - 1/16 in.	0	0	0	0	0	0	0.1	0.1	0.1	0.5	1.4	4.6	16.4	55.5
6	Paraffin dipped coats - 1/8 in.	0	0	0	0	0	0	0.1	0.1	0.1	0.3	0.2	0.3	0.3	30.6
7	Paraffin cast coating - 1/2 in.	0	0	0	0	0	0	0.1	0.1	0.1	0.3	0.4	0.7	0.8	28.8
8	Tube - 3/4 in. paraffin plugs	0	0	0	0	0	0	0.1	0.1	0.1	2.8	10.2	23.4	77.9	80.9
9	Tube - 3/4 in. beeswax plugs	0	0	0.1	0.2	0.3	0.7	1.1	2.1	3.2	10.4	18.3	24.0	30.9	78.4
10	Tube - 3/4 in. sealing compound	0	0	0	0	0	0.1	0.1	0.1	0.1	0	0	0.1	0	0
11	Tube - 1-1/2 in. paraffin plugs	0	0	0	0	0	0	0	0	0.1	0.2	1.8	3.9	13.7	80.6
12	Tube - 3/4 in. paraffin plugs, 3/4 in. plaster of Paris plugs — Gross	2.1	5.6	11.6	19.8	25.1	26.3	26.3	26.4	26.1	26.3	26.9	27.6	31.8	65.7
	— Net	0	0	0	0	0	0	0	0.1	-0.2	0	0.6	1.3	5.5	39.4
13	Tube - 3/4 in. paraffin and steel disk	0	0	0	0	0	0	0	0	0	0.4	0.7	1.5	5.5	72.6
14	Tube - 3/4 in. paraffin and tape	0	0	0.1	0.1	0.1	0.1	0.2	0.2	0.2	1.9	5.9	11.3	27.8	77.3
15	Tube - plain disk covers and tape	0.1	0.2	0.2	0.3	0.4	0.6	1.0	1.4	2.0	5.0	8.2	10.8	14.8	38.3
16	Tube - tight fitting caps	0	0	0	0	0	0	0.1	0.2	0.6	1.4	2.9	3.9	5.7	10.6
17	Tube - 1/64 in. paraffin, caps, vents	0	0	0	0	0	0.2	0.2	0.2	0.3	0.9	1.7	2.5	3.4	6.8
18	Tube - caps and rubber band	0	0	0	0	0	0.2	0.3	0.3	0.5	1.0	1.7	3.0	6.1	13.0
19	Tube - caps and tape	0	0	0.1	0.1	0.1	0.2	0.3	0.4	0.6	1.6	2.7	3.8	5.3	12.0
20	Tube - caps, tape, and vents	0	0	0.1	0.1	0.2	0.2	0.3	0.4	0.6	1.5	2.9	5.0	11.5	26.8

All samples remolded Boston Blue Clay; diameter 1.93 in., length 4.0 in. Tubes and caps of brass. Samples stored in horizontal position on open shelves in basement laboratory. In winter warm and dry with temperatures 20 to 25°C. In summer some exposure to sunlight, occasionally humid and temperatures to 35°C. After 5 to 6 months, wax paper and Cellophane fully deteriorated by fungus and chemical changes. Plastic flow of paraffin during warm summer months, causing decrease of thickness and ultimately pin holes in bottom cover in Tests 5, 6, 7, and air channels to be formed on top of paraffin plugs in Tests 8, 11, 12, 13, 14. Considerable corrosion of tubing and adhesion of soil in Tests 8, 9, 11, 12, 13, 14, 15, 20. Some corrosion and very strong adhesion in Test 18; rubber bands deteriorated in 10 months. No corrosion but some adhesion in Tests 16, 17, 19. No corrosion or adhesion in Test 10. In Test 12, gross indicates total loss of water from sample and plaster of Paris reinforcing plugs; net indicates loss of water from sample alone. Tests started Oct. 1942, terminated March 1946.

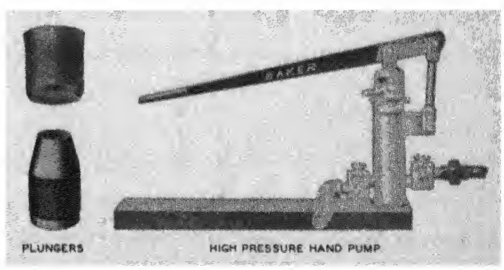
close and uniform fit. It is doubtful that such care in sealing always can be duplicated under field conditions Therefore, in some cases the loss of water may start earlier and the rate of loss be greater from samples sealed in the course of practical sampling operations than observed during these experiments.

The value of temporary protection against loss of water by covering or wrapping the sample in wax paper or Cellophane is demonstrated by Tests No 1-4. The rate of loss of water for a sample wrapped in wax paper is less than 1/10 of that of the unprotected sample, and the rate of loss by use of Cellophane is 3 to 8 times smaller than by use of wax paper The ends of the wax paper or Cellophane were merely bent over and tucked under the sample but not sealed by heat, cementing, or tape Contact with soil and some circulation of air caused development of fungus, chemical changes, and ultimately complete deterioration of both the wax paper and Cellophane Sealing of the free ends of the wax paper or Cellophane will undoubtedly greatly decrease the rate of loss of water and delay deterioration

16.2 Preservation of Rock Cores

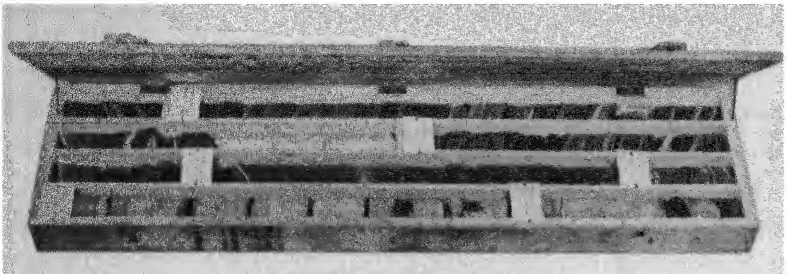
Cores of sound rock can generally be extracted from the core barrel without difficulty after the coring bit and core catcher unit have been removed However, cores of soft or broken rock are often jammed in the barrel, and considerable pressure may be required to push them out The upper end of the core barrel or inner tube is then connected to the circulation pump of the drilling machine or to a hand pump, and hydrostatic pressure is applied to the top of the core Pressures up to 5000 lb/sq in can be applied by special hand pumps, Fig 324-right.

It is advisable, and often necessary, to transmit the pressure through a self-sealing plunger in order to avoid leakage, piping, and damage to the core Special plungers with a steel core and rubber gasket or rubber plungers with a composition core, Fig 324-left, are used for this purpose When the hydrostatic pressure is applied by means of the circulation pump, the latter should be run slowly to avoid too fast movement and possible breaking and scattering of the core once the jam or hold on the core is broken For the same reason, all air over the core and in the pipe to the pump should be ejected and replaced with water before pressure is applied The core should be thoroughly cleaned after its removal from the core barrel



Rock cores of small diameter are preserved and shipped in boxes of wood or galvanized sheet metal, Fig 325 and 326 The boxes are generally from 3 to 5 ft long and are divided into compartments just wide enough to provide a snug fit for the core. The cores from each run are separated by wood blocks on which the depth

to the top and bottom of the core section are marked. Care should be taken to place the core and its individual sections with the top and bottom in correct posi-



WOOD BOX FOR ROCK CORES

FIG. 325

SHEET METAL CORE BOX

FIG. 326

tions The core box should be marked with project and boring number and the depths between which the cores in the box have been obtained Cores of soft formations and some rocks may disintegrate on exposure to air and free moisture and should be protected by coating with paraffin, Fig. 325-center, or a clear lacquer. Protection for shorter periods may also be obtained by wrapping the cores in Cellophane, Kodapak, Pliofilm, etc , and sealing the free ends of the wrapping material, or by placing the cores in sheet metal boxes and sealing the joints with adhesive tape. Rock cores of medium size, 4 to 12 in diameter, are usually stored on racks near the site of exploration, whereas very large cores often are left on the ground near the bore hole.

16.3 Preservation of Representative Samples

When maintenance of the original water content is not essential, large representative soil samples are generally preserved in bags of unbleached and tightly woven duck or light canvas cloth The seams should be double stitched to obtain adequate strength and tightness. The size of the bags is generally designated by the approximate number of pounds of soil, weighing about 100 lb/cu ft, which the bag contains when filled. Various sizes of such bags are shown in Fig. 327, and the corresponding flat dimensions are,

Nominal Size	lb	100	50	10	2	1
Flat Dimensions	in	16 5 x 33 5	14 x 21 5	7 x 16 5	5 5 x 12 5	4 8 x 9

Bags of intermediate sizes and containing 75, 25, or 5 lb of soil are also in common use Bags weighing 100 lb or more are hard to handle, and it is often found convenient not to fill the 100-lb bags completely or to use 75- or 50-lb bags. In general, the bags are easier to handle when they are only 2/3 to 3/4 full. Tying of the bags is facilitated when the center of a tie string is sewn to the bag at the proper distance from the top Untreated cloth deteriorates in contact with soil, and the samples cannot be stored in the commonly used bags for more than a few months

to a year When longer storage is contemplated, bags of mildew resistant cloth should be used, or the samples should be transferred to wood boxes or to kegs or barrels of wood or galvanized steel.

FIG 327 - BAG SAMPLES

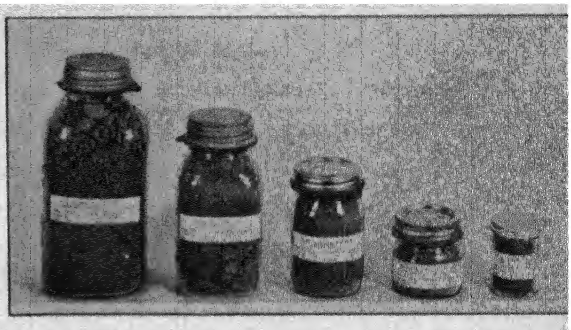


FIG 328 - JAR SAMPLES

When representative samples are to be preserved without loss of water, they are placed in glass jars with a gasket and a screw cover of coated sheet metal, brass, or aluminum, Fig 328 Cylindrical jars of 1/5- to 1/2-pint size are commonly used for preservation of small representative samples taken during reconnaissance explorations Small cans of galvanized or coated sheet metal are occasionally used for the same purpose

16.4 Dipping or Encasing of Samples in Paraffin

In spite of certain shortcomings of the method, large block samples and irregular chunk samples are generally preserved by dipping or encasing in paraffin, provided the soil is not so coarse grained and porous that the melted paraffin enters the sample Formerly, most samples taken with drive samplers of large diameter were removed from the sampling tube in the field and encased in paraffin, and this method is still used to some extent when the sampler is short and not provided with liners. The advantages and limitations of the method will be discussed after describing the details of the procedure

Removal from sampling tube.- Until recently, samples of large diameter were often removed from samplers without liners by applying air or water pressure to the top of the sample However, it is difficult to control the movements of the sample when air pressure is used, and water may cause an increase in water content, piping, and serious disturbance of the sample unless the pressure is applied to and transmitted by a piston with watertight packing. The revised M.I T. sampler, Fig. 191, is therefore provided with a piston and a short piston rod, which can be attached to a screw or hydraulic jack The sample in the Vicksburg sampler, Fig 185, is removed by placing the dismantled sampling tube on a close fitting piston and pushing the sample out through the top of the tube by means of a screw jack This method has the advantage that stresses in the sample are not reversed during removal, and that

the lower end of the sample can be trimmed properly before being placed on the piston When the end of the sample in contact with the piston is not plane and perpendicular to the axis of the sampling tube, plastic deformations will take place when pressure is applied, and a considerable part of the sample may thereby be seriously disturbed

Dipping in paraffin.- It is advisable to apply one or two preliminary paraffin coatings with a brush, since the paraffin then congeals rapidly, and its penetration into cracks or pores in the soil is decreased Brush coats are likely to contain air

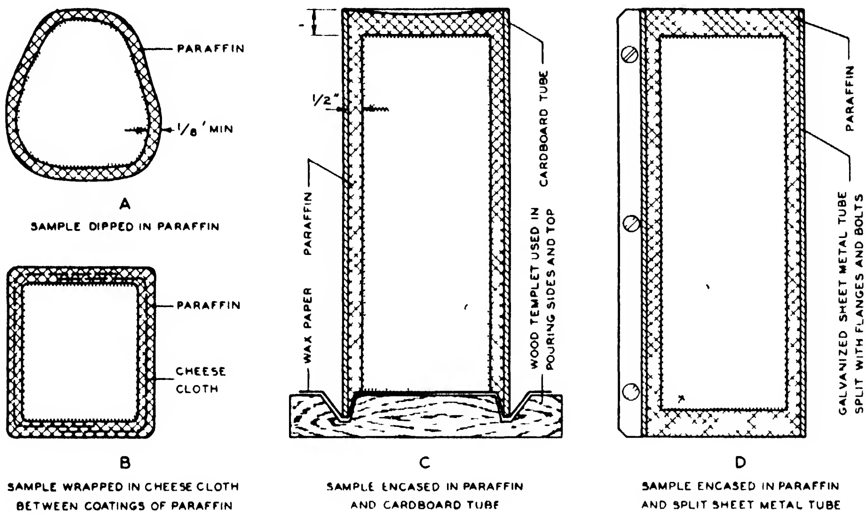


FIG 329 - PARAFFIN ENCASED SAMPLES

bubbles and pin holes and should be supplemented by dipping the entire sample into melted paraffin The temperature of the paraffin should be close to the congealing point, and the dipping should be repeated until the coat is about 0 1 in thick, Fig 329A Further protection, especially against cracking and deformation of the paraffin coat, can be obtained by wrapping the sample in cheesecloth after the paraffin coat has reached a thickness of about 1/16 in and then thoroughly soaking the cloth and increasing the coat thickness by additional dippings in paraffin, Fig 329B

Encasing in paraffin.- The dipping of very large samples in paraffin is inconvenient and often impossible to perform under field conditions Such samples are generally placed in an oversize box or container and the paraffin poured around them, Fig 321, but the cast paraffin coat is not as uniform and strong as that obtained by repeated dipping If the box is used only as a mold and removed in the field, the paraffin encased sample should be wrapped in cheesecloth and given several brush coats of paraffin When the soil is very coarse grained and porous, the sample may be covered with Cellophane or Pliofilm before the paraffin is poured around it.

Large cylindrical samples are generally placed in an oversize cardboard tube or a split cylinder of galvanized sheet metal, Fig 329C and D. The encasing in

paraffin is facilitated by use of a grooved templet or base plate, Fig 329C, devised by the **Waterways Experiment Station,** Corps of Engineers After the paraffin covering the sides and top of the sample has congealed, the tube with the sample is turned over, the templet is removed, and the bottom cover poured The cardboard tubes are cut open and discarded when the samples are to be tested in the laboratory, whereas the split sheet metal containers are opened up, removed, and used again The sheet metal containers are occasionally removed in the field after the paraffin has congealed, in which case the paraffin encased samples should be wrapped in cheesecloth and given several brush coats of paraffin, or they should be placed in individual containers and surrounded with sawdust, Fig 338B

Paraffin as a sealing material.- Paraffin is relatively cheap, readily available, and the most widely used material for sealing of soil samples, but it does have several undesirable properties It shrinks considerably when it congeals, it becomes brittle and may crack when cold, and it is soft and plastic, deforms, and difficult and time-consuming to use at high summer temperatures The shrinkage and the danger of penetration of paraffin into cracks and pores in the sample can be decreased by applying the paraffin after it has been allowed to cool to a temperature as close as possible to its congealing point However, when a very narrow space between the sample and a container is to be filled with paraffin, it must be heated well above the melting point so that it does not congeal before it reaches the more distant parts of the void, thereby leaving sections of the sample unprotected

Experiments with samples dipped or encased in paraffin indicated only a negligible loss of water during the first one to two years of storage, Table 13 -- Tests 5 to 7, but thereafter water was lost at a rapidly increasing rate The sudden increase in the rate of loss of water was caused by plastic deformations, which reduced the thickness of the paraffin coat below the cylindrical sample until small holes in the paraffin ultimately were formed Such plastic deformations can be reduced by avoiding stress concentrations in supporting the sealed samples and by protecting them against high temperatures One paraffin-dipped, square sample was stored for eight years without appreciable loss of water, but there are also many reports on samples drying out in less than one year of storage, although they were covered in the field with a 3/8 to 3/4 in thick, cast coat of paraffin and stored in a cool and humid room The causes of this loss of water have not been definitely established, but it is possible that voids or air spaces were formed in the paraffin cover and that shrinkage caused development of small cracks, especially at joints where melted paraffin had been poured on congealed and cool paraffin

The physical properties of paraffin may be improved for sealing purposes by mixing various grades of paraffin with different melting points and by admixture of Ceresine, Carnaubawax, or beeswax Systematic experiments are needed to determine the types of paraffin and admixtures which will produce the tightest, most resilient, and strongest coating for sealing of soil samples

General comments.- In spite of the shortcomings of paraffin as a sealing

material, dipping or encasing in paraffin is the best of currently available and practical methods for sealing large block samples and irregular block samples It is possible that some modern lacquers or sealing compounds of rubber and plastic materials may be used to advantage, and that they may furnish a tighter and more durable coat and be easier to apply at high summer temperatures Such compounds must not be too sticky or develop too great adhesion to the soil, since it then would be difficult to remove the coating without disturbing the sample

Removing soil samples from the sampler and preserving them by dipping or encasing in paraffin has the advantages that: (1) a thin-wall sampling tube can be used repeatedly, (2) the sample can be inspected and a more accurate boring log prepared in the field, (3) disturbed and undisturbed sections as well as coarse-grained and fine-grained sections of the sample can be preserved separately, and the danger of internal migration of water during storage is thereby decreased, (4) the sample is not in contact with metal, and the danger of chemical changes of the soil is reduced, and (5) the paraffin can be reclaimed and used again after the sample has been used for laboratory tests However, the method has the disadvantages that (1) the removal from the sampler and handling of the sample under adverse field conditions may cause serious disturbance of the sample and connot be accomplished safely when the soil is soft or cohesionless, (2) only short soil samples can be removed as a unit from a sampling tube, and the taking of short samples increases the cost of continuous sampling and decreases, relatively, the part of the sample which can be considered as being undisturbed, (3) encasing the sample in paraffin is often more time-consuming than preservation in the sampling tube or in liners, especially at high summer temperatures, (4) the paraffin coating does not always provide reliable protection against loss of water during protracted storage, and (5) the removal of a thick paraffin cover for examination and testing of the sample is time-consuming

16.5 Preservation of Samples in Long Sampling Tubes

When long, thin-wall sampling tubes without liners are used, the samples are generally preserved in the sampling tubes After the tube is disconnected from the sampler head, the gross length of the sample should be determined or checked. Seriously disturbed material from the upper part of samples taken with open samplers should be removed, and the bottom of the sample should be trimmed to a distance of at least 3/4 in from the cutting edge to make room for the sealing plug It is advisable to preserve the soil removed from the bottom of the sample in a glass jar, since such a small representative sample permits laboratory verification of the field classification and determination of the water content without removing the sealing plugs of the large sample The parts of the tubing which are to receive the sealing plugs should be thoroughly cleaned, since soil on the wall of the tubing will prevent formation of a good bond and a tight joint between the sealing plug and the tubing The net length of the sample should be measured after trimming and cleaning and before sealing.

Sealing with paraffin.- It is common practice to seal the top of the sample with a 1- to 2-in long paraffin plug, formed by pouring melted paraffin into the tubing. However, such a plug does not form a reliable seal, since the paraffin shrinks during congealing and cooling and may thereby break the bond and establish a slight clearance between the plug and the tubing When the tubing is shipped or

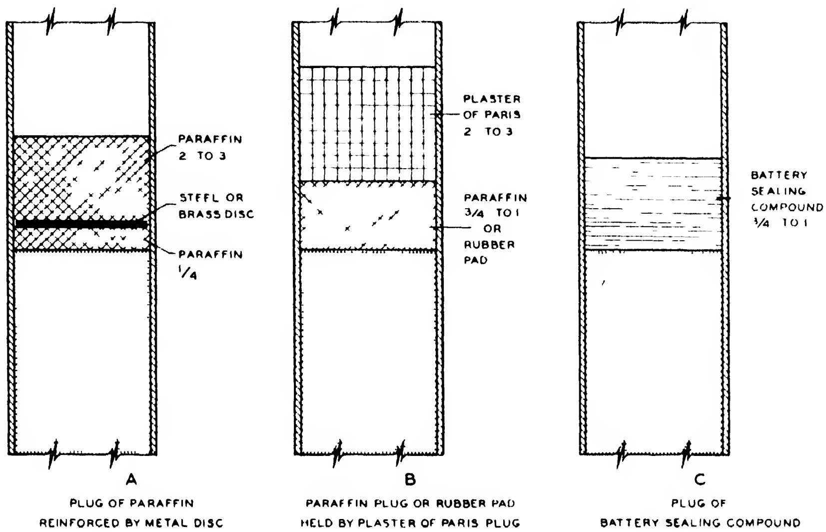


FIG 330 - SEALING PLUG IN SAMPLING TUBE

stored in a horizontal position and the temperature is high, the paraffin may undergo plastic deformations and thereby open a channel to the sample As soon as a crack or opening is formed, rapid loss of water occurs, Table 13 -- Tests 8 and 11. The deformations of a paraffin plug can be decreased and a fairly satisfactory seal obtained when the plug is reinforced by a metal disk, Fig 330A, or by an additional plug of plaster of Paris, Fig 330B Experiments with samples sealed in this manner indicated a negligible loss of water during the first 1-1/2 years of storage, after which cracks began to form and the rate of loss of water increased rapidly, Table 13 -- Tests 12 and 13 However, when the samples are sealed under field conditions, cracks may appear and loss of water start after a much shorter period of storage It should be noted that the plaster of Paris plug lost a considerable amount of water during storage, and that weighing of the sealed sample therefore cannot be used as a control test when plaster of Paris is used to reinforce the sealing plug

In warm weather, when the paraffin congeals very slowly and often not completely, the paraffin plug in Fig 330B may be replaced with a tight fitting rubber pad. However, direct contact between metal and vulcanized rubber may produce corrosion during protracted storage

The lower end of the tubing may be sealed in the same manner as the upper end, but as added precaution it is advisable to support or protect the paraffin plug

by adhesive or friction tape as shown in Fig 331A Cork or rubber stoppers are occasionally used for sealing the lower end of the tubing, and a flat disk or a cap as shown in Fig 332B and C may also be used when it is desired to avoid removal and waste of any material from the lower end of the sample.

Sealing with beeswax.- Experiments were made with 3/4-in thick sealing plugs of beeswax, Table 13 -- Test 9 There was no evidence of shrinkage cracks or plastic flow, even at temperatures occasionally reaching 35°C, but water was lost at a fairly uniform rate of 2 2 g per month, and the sample was completely dried out after 3-1/2 years of storage

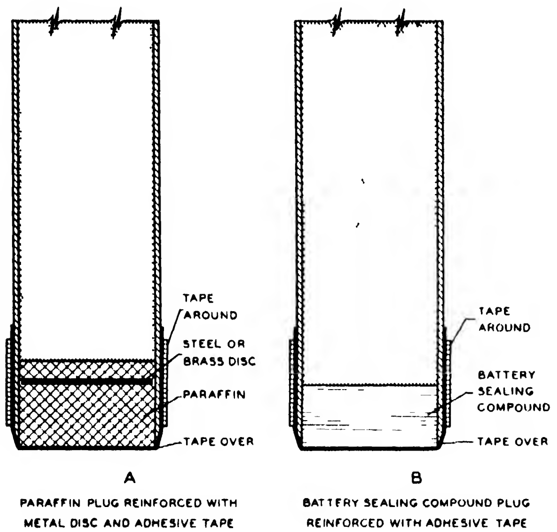


FIG 331 - SEALING OF END OF TUBE

Battery sealing compound.- In the experiments the best results were obtained by sealing with common battery sealing compound, Fig 330C and 331B There was no evidence of shrinkage, plastic flow, and movements of the plugs, and the loss of water was less than 0 1 g after 3-1/2 years of storage, Table 13 -- Test 10 This compound has an asphalt base with rubber and other ingredients, it is readily obtainable and relatively cheap The melting point of the compound is about 88°C, and it can be used without difficulty in hot weather, in contrast to paraffin It adheres very strongly to metal tubing, and a sealing plug of this material normally needs no additional support On the other hand, the stickiness makes it difficult to remove from the tubing and undesirable for direct coating of soil samples.

Samples of expanding soils.- Special precautions are required to prevent displacement of the sealing plugs when the sample consists of soil which tends to expand on account of gases entrapped in its pores or dissolved in the pore water This may, for example, be accomplished by supplementing both the top and bottom sealing plugs of paraffin or battery sealing compound with plugs of plaster of Paris. Displacement of the compound plugs during their congealing and/or setting should be prevented by means of clamps and wedges In laboratory experiments, plaster of Paris plugs developed a strong bond to the tubing, but when such plugs recently were used as supporting seals for samples of strongly and rapidly expanding soil, it was found that the plugs often were displaced during transportation and storage of the samples. It is possible that gases escaping from and expansion of the soil, or the presence of a film of oil or soil on the tubing, prevented formation of an adequate bond. Until further experiments have been performed, plaster of Paris

plugs cannot be considered as a fully reliable means of preventing displacement of the sealing plugs. It may also be possible to prevent expansion of the sample by filling empty parts of the tube above and below the sealing plugs with compacted soil and use of caps which are cemented to the tubing, see page 397.

Corrosion and adhesion.- When a sample is in direct contact with corrodible metal and especially steel, there is danger that electrolytic action may change the physical properties of the soil, and that corrosion may roughen the wall of the tubing or produce such a strong bond that the sample cannot be removed from the tubing without seriously disturbing the soil The degree and extent of the corrosion depends on the type of metal in the tubing, the soil constituents, and the salts dissolved in the pore water, and it is increased by the presence of air in an annular clearance between the sample and the tubing and especially by circulation of air through defective seals. The upper and often loosely fitting part of the sample is generally more affected by corrosion than the lower and tightly fitting part

Samples preserved in untreated steel sampling tubes, sealed with plain paraffin plugs, often show serious rust formations and strong adhesion between the soil and the tubing after only a couple of weeks storage Serious corrosion has also been observed after a few months storage of samples preserved in brass tubing but improperly sealed The degree of corrosion and adhesion of soil in the brass tubing used in the sealing experiments, Table 13, increased with increasing loss of water, but the tubing used in Test 10, effectively sealed with battery sealing compound, showed no signs of corrosion and adhesion of soil after 3-1/2 years of storage

Corrosion of steel tubing can be decreased by wiping the tubing with a rust prevention compound or by lacquering the tubing, see Section 9 7 Samples of soft clay, preserved for 7 months in lacquered steel tubing and sealed with paraffin plugs as shown in Fig 330A and 331A, were easily removed from the tubing and there were no signs of corrosion or adhesion of soil

16.6 Preservation of Samples in Short Tubes and Liners

This section deals with the preservation of samples in the short sampling tubes used in surface and control sampling and preservation in the liner tubes of drive samplers and core barrels The various types of liners used and their advantages and disadvantages are discussed in Section 4 11 The gross length of the sample should be determined or checked before the liner or liner sections are removed from the sampler The liner should preferably be removed by a push or pull on the liner itself although moderate pressure on the sample may be exerted through a piston in uniform contact with the top of the sample Considerable pressure may occasionally be required to remove the liner, and it should then be applied by means of a jack and transmitted through a drive ring or piston to the liner Hammering on the drive ring will cause vibrations and should be avoided. Application of great

pressure to the sample proper, whether through a piston or as hydrostatic pressure, should be used only in emergency

Sections of the sample above or below the liners are cut off and preserved by dipping or encasing in paraffin or placed in glass jars or metal containers with tight covers When sectionalized liners are used and each section is to be preserved separately, the sample should be cut with a wire saw, or with a hacksaw when the soil is very stiff or hard Seriously disturbed material should be removed from the top of the liner or upper liner section to avoid internal migration of water Before sealing, the net length of the sample should be measured carefully unless the sample is trimmed flush with the top and bottom of the liner section When required, other control measurements and tests should be performed on the individual sections as described in Section 16 13

Wax paper and Cellophane.- Temporary protection against evaporation may be obtained by covering the ends of the tubing with wax paper, Cellophane, or Pliofilm, held in place by rubber band, Fig 332A This method may be used when the samples are to be removed from the tubing within a few hours or until control tests can be performed and the permanent sealing completed

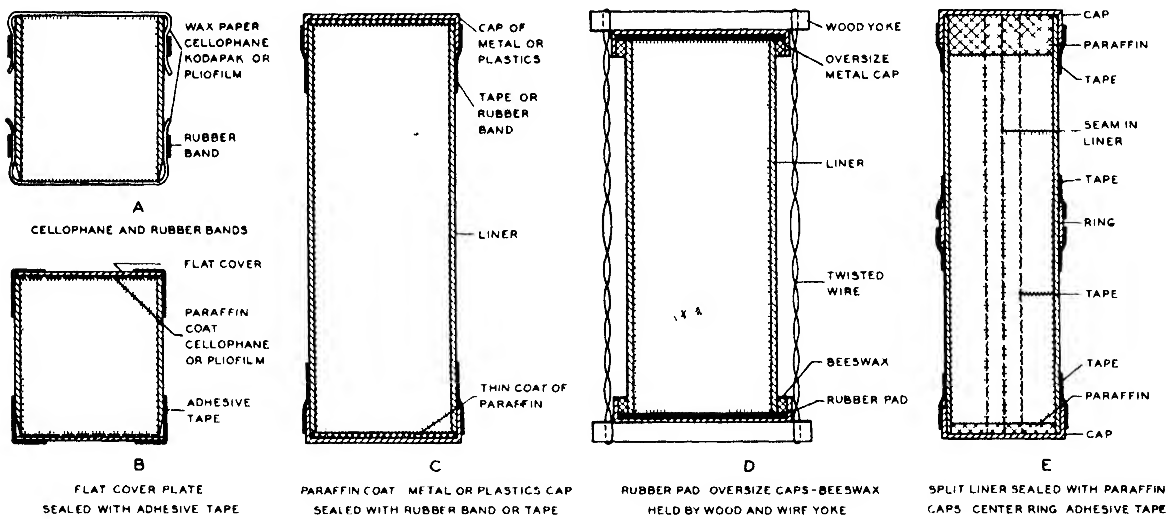


FIG 332 - SEALING OF SHORT TUBES AND LINERS

Very long or short liners.- Long continuous liners are often sealed by the methods used for long, thin-wall sampling tubes and described in Section 16 5. Liners which are divided into very short sections, so that the sample can be tested without being removed from the individual sections, Fig 241 and 245, are usually preserved as a unit and placed in a metal tube with gaskets and a tight-fitting cover or screw cap. The short sampling tubes used in surface and control sampling are occasionally placed in metal containers with rubber pads at top and bottom and a screw cap, Fig 311D, but are usually sealed by means of plain disks or caps

Plain disks and tape.- Support of samples of soft or cohesionless soils and

protection against excessive loss of water for several days to several weeks can be obtained by means of plain metal disk covers and adhesive or friction tape as shown in Fig 332B A preliminary thin coating of the ends of the sample with paraffin will provide added protection, if the soil is too porous for use of paraffin, a sheet of rubber or Pliofilm may be used instead Experiments with 2-in samples sealed with plain disks and tape but without the preliminary coating with paraffin indicated a loss of water of 0 9 to 1 3 g per month, Table 13 -- Test 15 In similar experiments with 3-in samples the rate of loss of water was 1 0 to 1 4 g per month

Sealing with caps.- Caps of metal or plastic materials are generally used for more permanent sealing of short tubes and liner sections The joint between the cap and the tubing may in turn be sealed with tape, a rubber band, paraffin, or battery sealing compound, Fig 332C Adhesion between the cap and the sample may be prevented and a better seal obtained, in case the cap is not tight fitting, by preliminary coating of the ends of the sample with paraffin The paraffin should be applied hot so that it will not congeal before the cap is placed and so that it will be forced into the clearance between the vertical sides of the cap and the tubing

When a tight fitting cap or a cap with a coating of paraffin or sealing compound is used, air will be trapped between the cap and the sample, and it is often difficult to force the cap completely into place When the air is forced out, it may leave an unsealed channel, and the sample is then not properly sealed If air remains under the cap, it will increase the danger of corrosion, and it will be subject to volume changes by variations in temperature or pressure on the cap and may eventually break the seal A channel left by escaping air can often be closed by rotating the cap after it is in place A small vent may also be provided in the cap and sealed with tape after the cap is placed on the tubing Oversize caps have been used in some cases, and the clearance between the cap and the tubing is then filled with paraffin, beeswax, or a sealing compound, Fig 332D

In the experiments with samples preserved in the above mentioned manner, Table 13 -- Tests 16 to 20, the loss of water varied from 0 2 to 0 6 g per month After 3-1/2 years storage the samples had lost from 10 to 30 percent of their water content, they were hard to remove from the tubing which showed some corrosion and considerable adhesion of soil The caps had a fairly tight and uniform fit, and definite conclusions concerning the effect of additional sealing with paraffin, tape, and rubber bands cannot be drawn from the results of these experiments It appears that the loss of water was governed by accidental irregularities and leaks, as evidenced by the fact that several samples were dried out at one end only It is possible that better results would be obtained if the caps have an easy fit and are sealed with battery sealing compound

Expanding soils.- When the sample consists of soil which tends to expand, the caps may be pushed off the tubing during shipment and storage of the sample As suggested by the **Fort Peck District**, Corps of Engineers (110), the caps may be held in place by means of yokes and twisted wires, Fig 332D It is also possible

that sealing of the caps with battery sealing compound or a plastic cement would provide a bond strong enough to prevent dislodgement of the caps Before the cap is removed, the sealing and cementing agent could be softened by heating or dissolved by means of carbon tetrachloride, gasoline, or the thinner used for the plastic cement

Split liners.- Split liners are often placed in special metal shipping tubes with caps and gaskets, but they may also be sealed with caps as a solid-wall liner The longitudinal seam is then covered with tape, and it is advisable to add circumferential bands of tape or a center ring to lessen the strain on the longitudinal tape, Fig 332E The longitudinal seam will, of course, increase the danger of leakage

Partially filled liners.- When the length of the sample is smaller than the length of the liner section, the empty end of the tubing may be sealed with battery sealing compound or paraffin, reinforced with a metal disk or a plug of plaster of Paris as described in the foregoing section The sample may also be covered with a tight fitting rubber pad or a relatively thin plug of paraffin or battery sealing compound, held in place by filling the remaining part of the liner with tamped sand and closing it with caps and tape When the length of the sample in the liner is small, it is generally pushed out and preserved by dipping or encasing in paraffin

When a sampler with excessive inside clearance is used, there is often a small annular clearance between the sample and the upper liner section or sections It is very difficult to fill such a small clearance completely with paraffin, and any remaining air spaces will accelerate corrosion and deprive the sample of adequate support during shipment Under such conditions it is best to remove the sample from the liner, place it in an oversize container, and encase it in paraffin

Corrosion and adhesion.- The comments on corrosion and adhesion, made in the foregoing section, apply also to preservation of samples in liners As additional precaution against electrolytic action, disk covers and caps should be made of the same material as the liner or of electrically inactive materials such as plastics Reference is made to Sections 4 11 and 9 7 for comments on various materials used for liners and on oiling, galvanizing, lacquering, and other means of retarding or preventing corrosion

16.7 Marking, Shipping, and Storage of Samples

Marking of samples.- All samples should be properly marked so that there can be no doubt about the origin of the sample and, in case of tube and undisturbed samples, of its top and bottom

The marking may be written directly on the paraffin cover or the sample container with a porcelain marking crayon or with non-washable paint or lacquer. It may also be written on a label which is embedded in the paraffin and pasted on the container or on a tag which is attached to the container or bag. The writing should be made with non-washable and non-fading ink Pencil notes and typewritten data

may fade and become illegible in case of wetting or protracted storage The writing may be protected by coating it with paraffin but preferably with a clear lacquer or by placing the identification tag in an envelope and attaching the envelope to the container or bag In the latter case tags with the dimensions of standard filing cards are often used and placed in the files after the sample arrives in the laboratory or has been tested, so that the original field data instead of transcriptions are readily available

Representative samples in glass jars are usually identified by means of a label, Fig 328, and samples in bags by a tag or a filing card in an envelope The label or tag should contain data on the location and project number, boring or test pit number, sample number and depth, type of soil, and date of sampling

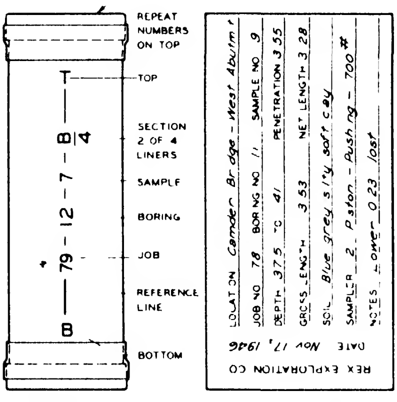
Samples preserved in long, thin-wall sampling tubes are marked with a tag, or a card in an envelope, attached to the tube and often partially folded and inserted in the upper and empty end of the tube In addition, the boring and sample number are often written or painted directly on the tubing The tag or card should contain the data indicated above for representative samples, but as shown in Fig 333A, it is desirable to supplement this information with data on the penetration, gross and net lengths, type of sampler, method of driving, and penetration resistance, even though this information also is contained in the boring and sampling records

Large-diameter samples encased in paraffin or preserved in liner sections are generally marked with pasted-on labels giving complete details, but the marking is also often confined to project, boring, sample, and section number, Fig 333B, written or painted directly on the paraffin cover or the container The top and/or bottom of the sample should be clearly indicated even when a convention, such as writing in the direction from bottom to top or on the top of the sample, is followed The identification is occasionally placed only on the top of the sample, but it is better to place or repeat the data on the side of the sample, so that it can be identified even after the cap or top cover is removed

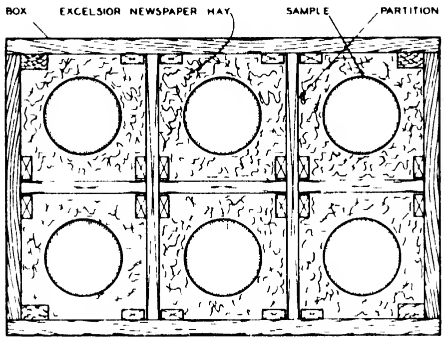
When a sectionalized liner is pushed out of the sampler, it is advisable to mark the individual sections with a longitudinal reference line, Fig 333B, so that the sections can be oriented in their original relative positions when the samples are sliced in the laboratory for examination of the stratifications and determination of the dip and strike, see Section 16 10 and Fig 350

Packing and shipment.- The shipment of representative samples does not require special precautions as long as the glass jars or bags are protected against actual injury and against excessive moisture which may cause deterioration of labels, tags, or bags Samples in glass jars are generally packed in the same cardboard containers in which the jars are furnished by the manufacturer Bag samples may be transported in private vehicles without special protection, but they should be placed in wood boxes when shipped by common carriers, or the samples should be preserved directly in wood boxes

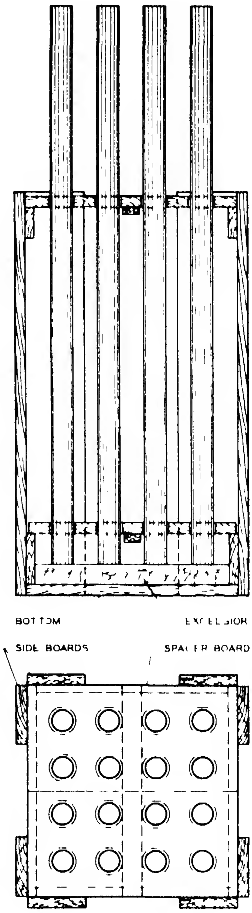
In contrast to representative samples, the usefulness of undisturbed samples may be seriously impaired by disturbance of the soil during transportation and shipment Such samples should at all times be effectively protected against freezing



MARKING OF SAMPLES
FIG 333

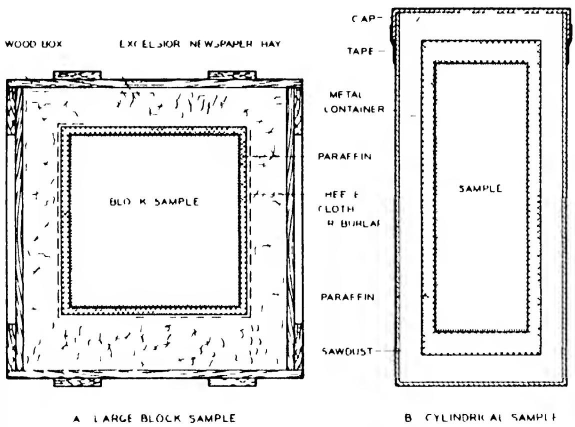


PACKING OF SHORT LARGE SAMPLES
FIG 337



RACK FOR LONG TUBES
FIG 335

SLUMPING OF SAND SAMPLE
DURING SHIPMENT
FIG 334



PACKING OF PARAFFIN ENCASED SAMPLES
FIG 338

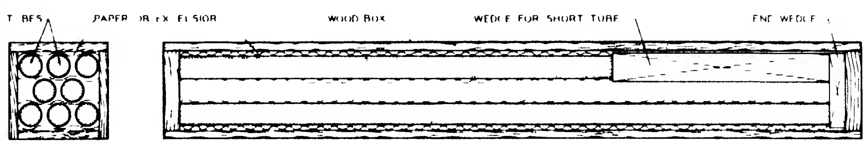


FIG 336 - BOX FOR LONG TUBE SAMPLES

and, insofar as possible, against vibrations and shocks When samples are transported in private vehicles, it is advisable to place them on a layer of excelsior or on a mattress to dampen vibrations The effect of vibrations is particularly serious when samples of soils with little or no cohesion are shipped in horizontal position. The vibrations may cause compaction and partial liquefaction of the soil, distortion of the soil layers, flattening of the top side of the sample, Fig 334, and may even cause dislodgement of a paraffin sealing plug Even when there is no visible flattening

or distortion of the sample, a closer inspection will often reveal that originally straight and smooth boundaries between soil layers show small irregularities and have acquired a slightly dentated appearance Whenever possible, the samples should be transported and, in general, at all times kept in upright position A rack for transportation of long tube samples in upright position, originally suggested by the **Providence District,** Corps of Engineers, **Fahlquist (120),** is shown in Fig 335

There is always danger that transportation in vehicles over long distances, in spite of all precautions, will cause vibrations and some disturbance of samples of loose, sandy or silty, cohesionless soils Therefore, samples of such soils, intended for accurate laboratory determination of the physical properties, should be tested in a laboratory on or very close to the site of the borings

In shipment by common carriers it is generally impossible to keep long tube samples in upright position, and the tubes should then be packed in strong wood boxes, adequately braced against displacement, and separated by excelsior, corrugated cardboard, or several layers of paper, Fig 336 Undisturbed samples of large diameter and preserved in relatively short liner sections should be packed for shipment in upright position and surrounded by excelsior or shredded paper, Fig 337 Large block samples should likewise be packed in wood or strong cardboard boxes and surrounded by vibration dampening material, Fig 338A Cylindrical, paraffin encased samples may be packed in individual sheet metal containers and surrounded by sawdust, Fig 338B, or placed in wood boxes as the samples shown in Fig 337 In cases where the shipping distances are relatively short and the shipping boxes are used frequently, it is often advantageous to avoid removal and repacking of the padding material by covering it with burlap or light canvas, leaving holes into which the samples fit snuggly

Inspection and storage.- When the samples arrive in the laboratory, the sealing and marking should be checked carefully, and any defects should be remedied before the samples are placed in storage The weight of a sealed sample should be checked if this weight has been determined in the field as a control test

The samples should be stored in a cool but also frost-free room and preferably in upright position If there is any doubt about the effectiveness of the sealing, the samples should be stored in a room in which the humidity is kept close to 100 percent, or they should be placed in boxes and surrounded by sawdust, continuously kept moist High humidity will retard loss of water from soil samples but cannot always prevent it, and it is better to seal the samples properly than to rely on storage in a humid-room or in wet sawdust to prevent loss of water In cases where the temperature and humidity in the storage room reaches levels which promote growth of fungus, it is advisable to retard such growth by means of ultraviolet light

In spite of all precautions, there is always danger that a loss of water and that chemical and physical changes of the soil may take place during protracted storage Therefore, samples should be tested as soon as possible after their arrival

in the laboratory, and control tests should be made in case they may be stored for long periods

16.8 Removal of Seals and Containers

Before removing a sealing cover or container from a sample and preparing it for laboratory examination and tests, the seals and container should be examined for signs of leakage and corrosion, and any defects should be noted in the sample record. The weight of the sealed sample should be checked, if it has been determined in the field or before storage as a control test

Removal of paraffin cover.- The top and/or bottom covers of paraffin encased, cylindrical or block samples are removed first If the paraffin adheres to or has penetrated slightly into the soil, the sample should be cut with a wire saw just below the paraffin V-shaped cuts are then made in the paraffin covering the sides of the sample, so that the cover is divided into strips Each strip can often be removed as a unit, but it should be cut into short sections when the paraffin adheres to the soil In general, attempts to remove a large section of the paraffin cover as a unit may cause parts of the sample to be torn out

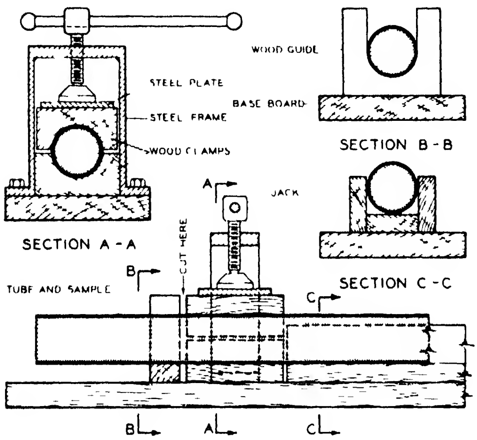
Removal of caps and sealing plugs.- Caps should be removed from the tubing by pulling or prying rather than by tapping which may cause disturbance of samples of cohesionless soils The sealing plugs at the lower end of long sampling tubes or liners can usually be removed without difficulty with a knife or screw driver If a plug of paraffin or sealing compound is held in place by a retaining plug of plaster of Paris, it may be necessary to drill holes in the latter and split it into several sections before it can be removed, but it is generally simpler to cut off the section of tubing containing the plaster of Paris plug Before removing the upper sealing plug, the top of the tubing should be cut off slightly above the sample, the location of the cut can be determined by the net or gross lengths of the sample as given in the boring record or on the identification tag After removal of the sealing plugs, the net length of the sample should be measured and compared with the field measurement

Cutting long tubes into sections.- Samples preserved in long tubes or liners can seldom be removed as a unit without disturbing the soil, and they should be cut into sections with a length of 3 to 6 times the diameter Longer sections may be used when the soil is firm and the inside friction relatively small The location of the cuts should be marked on the tubing and the various sections marked with section numbers, top or bottom, and also with a longitudinal reference line so that the sections later can be oriented alike during slicing of the samples and examination of stratification, see Section 16 10

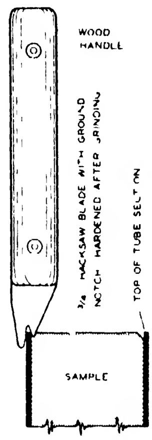
The cutting is most conveniently performed with a hacksaw which should have fine teeth, 32 teeth per in , in order to lessen vibrations The tubing should be held firmly, and the cuts should be straight and perpendicular to the axis of the tubing. A combined clamp and miter box is shown in Fig. 339. It is preferable, especially

in case of samples of large diameter, that the hacksaw be used only to cut the tubing and that the sample proper be cut with a fine wire saw It is possible that vibrations can be reduced and a smoother cut obtained by cutting the tubing with a small and very thin emery wheel rotating at very high speed, and that burrs and disturbance of the sample can be avoided by barely cutting through the tubing and completing the cutting with a short, thin knife, or a razor blade

After completion of the cutting, the burrs should be removed from the top of each section by means of a scraper, Fig 340, or similar tool If the cut at the lower end of a section is not straight and at right angle to the axis of the tubing, the end of the sample should be trimmed carefully with a glazier's knife It is very impor-



CLAMP AND GUIDE FOR CUTTING TUBING
FIG 339



BURR SCRAPER
FIG 340

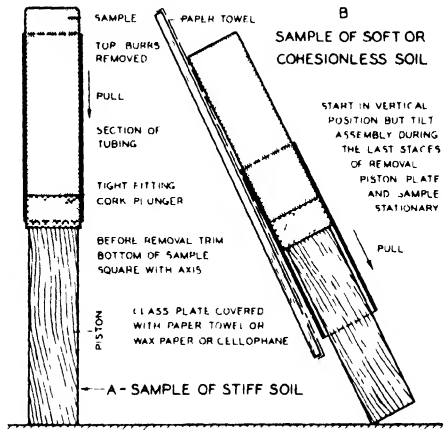
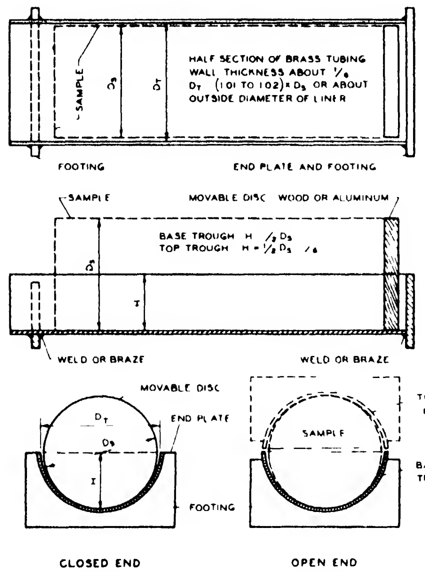


FIG 341 - REMOVAL OF TUBING BY HAND

tant that the lower end of the sample is plane and perpendicular to the tubing, since pressure exerted by the plunger during removal of the tubing otherwise will cause plastic deformations and serious disturbance of the lower part of the sample section This requirement applies, of course, also to samples preserved in short tubes or liner sections The upper end of the sample section should be marked with a line from the reference line on the tubing to the center of the sample, this line then serves as a reference line after the tubing has been removed

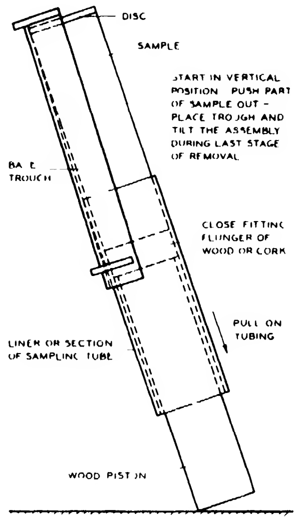
Removal of tubing.- To remove the tubing, the lower end of the sample section is supported on a plunger or piston, preferably capped with a tight fitting cork disk It is desirable that the sample be pushed out of the tubing in the same direction it entered the tubing in order to avoid increased disturbance by a reversal of the stresses caused by the inside friction Samples of stiff soils may be pushed completely out of the tubing and then transferred by hand to a slicing board or trough, but samples of soft or cohesionless soil should be supported during the removal A glass or plywood plate, covered with a paper towel, wax paper, or Cellophane, is placed along the tubing, and the entire assembly is tilted during the last stages of removal so that the sample gradually is transferred to the plate, Fig 341 The

plate, plunger, and sample remain stationary while the tubing is being pulled down A movement of the sample with respect to the paper covered plate will mobilize friction and may cause deformation of the sample When removing the tube or a liner section from a sample of large diameter, it is best to use a supporting trough as shown in Fig 342 and 343 Such a trough or troughs are also convenient for use in horizontal or vertical slicing of the sample, Section 16 10



SUPPORTING AND SLICING TROUGHS

FIG 342



USE OF TROUGH IN REMOVING SAMPLES FROM TUBING

FIG 343

When the sampling tube has correct inside clearance at the cutting edge, and the adhesion between soil and metal has not been increased by drying and corrosion, the tubing can generally be removed without exertion of great pull or pressure However, it does occur that the sample is so tightly lodged in the tubing that it cannot be removed by hand Jacking must then be used, but it should be realized that the sample often will be disturbed when great force is required to remove it from the tubing

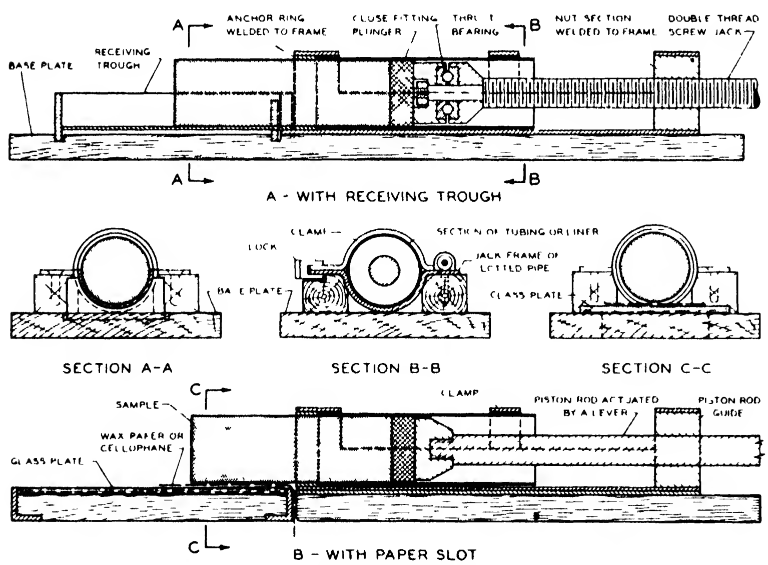


FIG 344 - JACKS FOR REMOVAL OF SAMPLE

Many types of special jacking arrangements have been devised for removal of samples from tubing or liners A couple of relatively simple designs are shown in Fig 344 The tubing is clamped and remains stationary while the sample is being pushed into a receiving trough or onto a plate The friction and adhesion between the soil and the trough or plate, Fig 344A, may cause deformation of samples of soft or cohesionless soils By pushing the sample onto a strip of paper or Cellophane which

enters through a slot in the base board, Fig 344B, the friction and adhesion between soil and metal are replaced with the smaller friction between the paper or Cellophane strip and the oiled metal or glass surface Transmission of the corresponding force to the sample may be prevented by attaching the end of the paper strip to a frame which is moved forward by the piston

Split liners.- The tape or solder sealing the seam of a single split liner and the caps, rings, and tape which hold the two halves of a double split liner together should be removed in order to relieve the internal forces and facilitate removal of the sample The sample can now be pushed out as from a solid-wall liner, or the half section of a double split liner may be removed by a longitudinal pull, but attempts to lift this section or to open the seam of a single split liner will often result in parts of the sample being broken off and even in splitting the sample

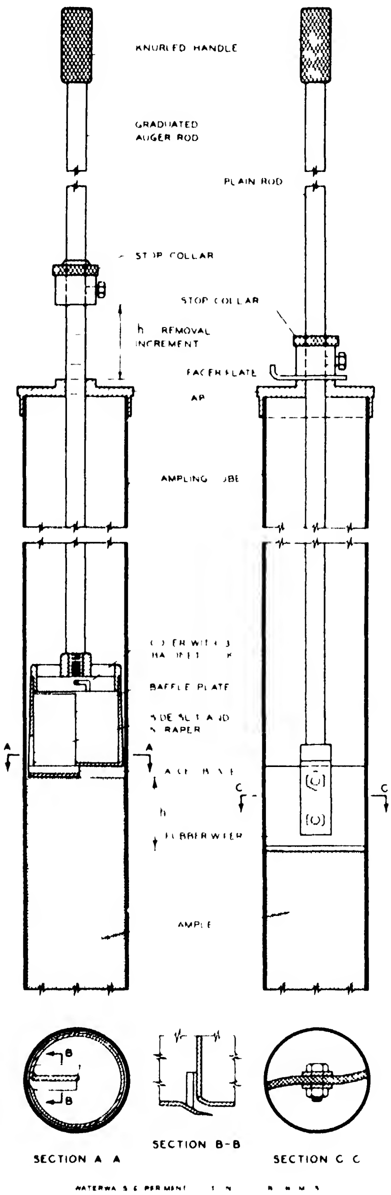
Cohesionless soils.- Samples of fully saturated, cohesionless soils may collapse during removal from the tubing or liner section It is suggested that a partial vacuum be applied through a porous disk in contact with the lower end of the sample and that a small quantity of water be extracted before or during removal of the sample The resulting capillary forces in the partially saturated soil will provide some apparent cohesion which may permit removal of the sample without serious structural disturbance The change in water content must, of course, be taken into consideration or the sample must be re-saturated before testing

Testing without removal from tubing.- Permeability tests are often conducted with the sample remaining in the tube or liner section, but disturbed soil close to the cuts is first removed When a sectionalized liner with very short sections is used, the sample is cut with a wire saw at some of the circumferential joints, and the individual section or sections are fitted into consolidation or shear testing apparatus, and the tests are performed without removing the sample from these sections Disturbance caused by trimming of test specimens and by a poor fit in the testing apparatus is thereby decreased This method of preparing and transferring test specimens to the testing apparatus has decided advantages, but a liner divided into very short sections requires considerable wall thickness, and similar short sections cannot be cut from a thin-wall sampling tube or a continuous liner by means of a hacksaw without disturbing the sample or test specimen However, it may possibly be accomplished by use of a thin emery wheel rotating at very high speed as described on page 403

Protection after removal.- When only a part of a sample is needed for a particular test, the remaining part is often left in the tubing or paraffin cover and re-sealed Pending testing, the removed sample or part of a sample may be protected for several hours against loss of water by wrapping it in wax paper or Cellophane, Table 13 -- Tests 3 and 4 Further protection is obtained by placing the wrapped sample in an airtight container with moist cotton or wet paper towels. However, when a part of a removed sample is to be preserved for more than a few hours or at most a couple of days, it is best to dip or encase it in paraffin

16.9 Removal of Sample in Increments

Cutting a long sampling tube or liner into sections will cause some vibration and may thereby disturb samples of cohesionless soils. When it is desired to perform triaxial, direct shear, or consolidation tests on undisturbed samples of cohesionless soils, the samples should preferably be obtained in test pits by means of advance trimming or block sampling methods. However, when the void ratio and unit weight of the soil in situ are of primary interest, and when other laboratory tests are to be performed on remolded soil, the sample may be removed from the tubing in small increments of controlled height and volume by means of a cup auger.



CUP AUGER AND WIPER
FIG 345

A cup auger developed by **John Ranttila** of the **Waterways Experiment Station**, Corps of Engineers, is shown in Fig 345. The auger is fastened to a graduated stem by bayonet locks so that it easily can be disconnected for emptying and cleaning. The wall of the cup is slightly tapered to avoid wedging of sand grains. The side slot and scraper serve to remove soil which may have entered the annular space or adheres to the wall of the tubing. A baffle plate prevents soil from accumulating over the entrance slot in the bottom. The height of the increments in which the sample is to be removed is controlled by a stop collar and a cap for the tubing.

To start the operation, the auger is lowered to the top of the sample and the stop collar is clamped at a graduation mark a short distance above the cap. The auger is rotated until the stop collar is in contact with the cap, whereupon it is withdrawn, emptied, and again inserted for final trimming of the soil surface. The stop collar is now moved upward for the desired increment, h, and the auger is lowered and rotated until the stop collar again is in contact with the cap. The auger is then withdrawn, emptied, and inserted for final trimming, whereupon the entire operation is repeated. The wet and dry weights of each sample increment are determined and the volume computed from the increment, h, and the diameter of the tubing.

When the soil tends to adhere to the wall of the tubing and greater accuracy is desired, the wiper shown to the right in Fig 345 may be used for final cleaning after removal of a sample increment. The wiper is lowered until it touches the top

of the sample, the stop collar is clamped in contact with the cap, and the wiper is raised a little by inserting a spacer plate between the stop collar and the cap The wiper is now rotated, then withdrawn, and the auger is again inserted for removal of soil which has been swept off the wall of the tubing A rubber wiper could also be built into the wall of the cup auger, but the connections complicate the emptying of the auger, and the side slot and scraper will usually clean the tubing satisfactorily

The increment, h, is generally between 1-1/2 and 2-1/2 in , depending on the detail and accuracy desired When the probable error in measuring h is Δh, the corresponding error, Δe, in determination of the void ratio, e, is approximately

$$\Delta e = \pm \frac{\Delta h}{h} (1 + e)$$

An increase in h will increase the accuracy with which the average void ratio of an increment is determined, but variations in the actual void ratio may remain undetected when h is too large The error in measuring h can be decreased by use of a secondary stop collar, and a spacer bar with the length h The spacer bar is placed on the primary collar, and the secondary collar is clamped in contact with the top of the spacer bar The bar is then removed, and the primary collar is moved up into contact with the secondary collar

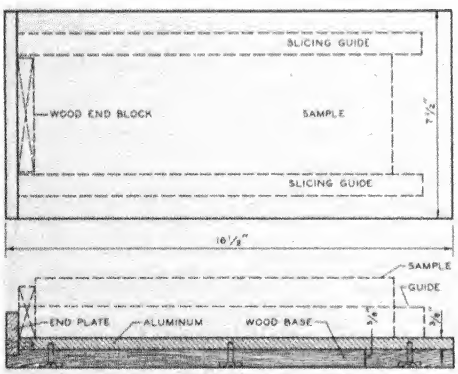
16.10 Visual Examination and Slicing of Samples

The general purposes of the slicing and visual examination of samples are, first, to check field soil classifications or establish the detailed soil profile and, second, to estimate the condition of the sample and select the parts most suitable for detailed laboratory tests After the preliminary examination, it is generally advisable to increase the visibility of stratifications, distortions, planes of failure, and other irregularities by methods described in Section 16 11 and in many cases also to obtain a permanent record by preserving or photographing some of the sliced sections The estimate of the condition of the sample should be based not only on the results of the visual examination but also on the recovery ratios and other field observations and on the results of control tests performed The type and condition of the sealing of the sample and difficulties in removing the paraffin cover or the container should also be noted and taken into consideration

Surface examination.- The tube or liner sections should be examined for corrosion and adhesion of soil The cutting edge of a thin-wall sampling tube should be inspected for dents which may indicate the presence of stones in the soil and disturbance of the sample In many cases it is also desirable to measure the diameter of the cutting edge and check the inside clearance The surface of the sample should be examined for stratifications, distortions, planes of failure, surface and shrinkage cracks, pitting, discoloration, and other signs of corrosion and drying. An experienced operator can often detect disturbed sections by the "feel" of the sample or a slight pressure with the fingers

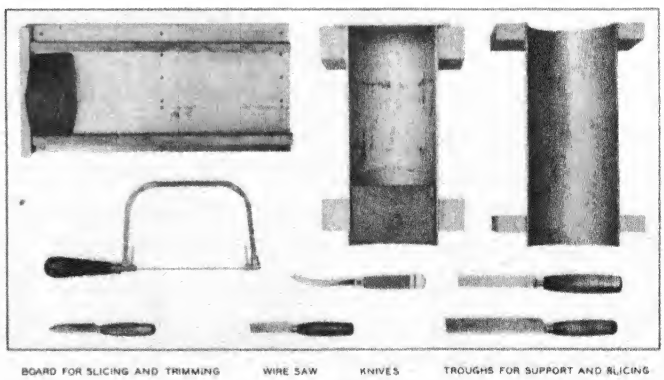
Slicing -- general.- The surface of a sample is generally covered with a thin layer or "smear" of disturbed soil which obscures stratifications and manifestations of general disturbance, and a reliable examination and visual determination of the condition of the sample requires removal of the disturbed surface layer or slicing of the sample or parts thereof Control and consistency tests should be performed before the longitudinal slicing of sample sections, at least when the diameter of the sample is less than 4 in

When the principal object is to determine the detailed soil profile, all sample sections are sliced longitudinally through the center One half of each section is used for minor physical or classification tests, whereas the other half is preserved for partial drying, trimming, detailed examination, and in some cases photographing When the object is to investigate the condition of the sample and to select sections for major physical tests, it is advisable to slice the top and bottom sections of long samples Normally, these sections should not be used for major physical tests since they often are partially disturbed, see Section 6 9 If the entire top and bottom sections show distortions and/or planes of failure, the adjoining sections should also be sliced and examined When there are no visible signs of disturbance in the lower or upper part of the sliced sections, respectively, it is generally safe to conclude that there are no distortions or planes of failure in the intermediate or central sections of the sample When preparing test specimens from selected sections, it is often advisable to slice and examine and in many cases to photograph smaller parts of the sample immediately above or below the test specimen or to slice and photograph the test specimen after the test



BOARD FOR SLICING AND TRIMMING SAMPLES

FIG. 346



SLICING AND TRIMMING EQUIPMENT

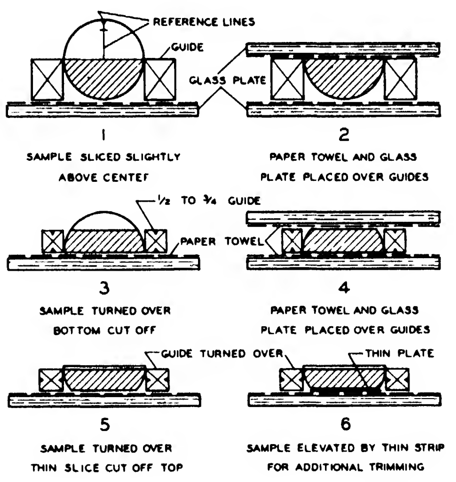
FIG. 347

The principal equipment required for slicing and trimming of samples consists of pairs of troughs, for large samples, with diameters corresponding to those of the samples, Fig 342, a fairly heavy slicing board with an end plate and covered with aluminum, brass, or a plastic material, Fig 346, several wire saws, guide strips, and assorted knives, Fig 347 Cobbler's knives with a straight edge, lower right in Fig 347, are excellent for rough trimming, but knives with a curved edge or blade are generally needed for the final trimming

Cross-sectional slicing.- Horizontal or cross-sectional slices are cut by means of a miter box or a pair of troughs, Fig. 342 After the sample is transferred from its container to the base trough, Fig 343, it is pushed forward by means of the movable end disk until it projects the desired amount beyond the open end of the trough The top trough is then placed on the sample and its open end lined up with the end of the base trough, whereupon the cutting is made with a wire saw, and the slice is transferred to a plate covered with a paper towel The troughs should be tilted when the soil is soft, and the slice should be transferred in a sliding movement

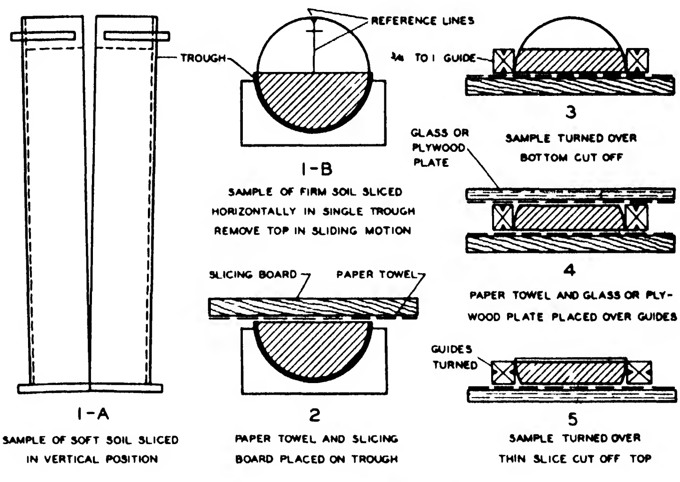
Cross-sectional slices are easy to prepare and cause comparatively little waste of sample material They often permit direct determination of the strike of inclined strata, and the presence of rings in such slices indicates serious distortion of the soil layers, Fig 142 However, when the soil layers are thick compared to the degree of distortion, the cut may pass entirely through a single soil layer, and a slice of uniform appearance is then obtained Therefore, the absence of rings in the slices does not guarantee that the soil layers are not distorted, and cross-sectional slicing should be supplemented by longitudinal slicing

Longitudinal slicing.- The procedure in slicing sample sections longitudinally is shown in Fig 348 and 349 After the cut is made, the upper half of the sample



PROCEDURE IN SLICING SMALL SAMPLES

FIG 348



PROCEDURE IN SLICING LARGE SAMPLES

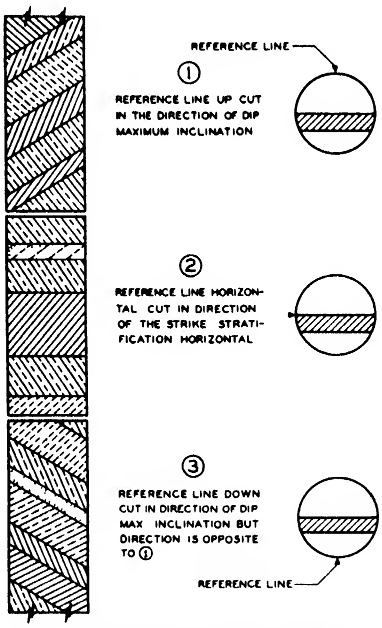
FIG 349

should be removed in a sliding movement; if it is lifted off and the soil is sticky, parts of the lower half of the sample may be broken off When the diameter of the sample is large, it is advisable to make the first cut with the troughs in vertical position and to move them slightly apart as the cutting proceeds, Fig. 349-1A. It is sufficient to cut the sample into halves when the object of the slicing is only a rough inspection for distortions or a check on the soil profile, but slices with a uniform thickness of 1/2 to 3/4 in. are easier to dry and handle and should be prepared when sections of the sample are to be partially dried and trimmed for detailed examination and perhaps photographing The number of the sample and the section, and

also the position of the top or bottom of the section, should be marked on the bottom of each slice.

When it is desired to preserve a long sample as a unit, the entire tube with the sample may be divided into halves without first cutting the tubing into short sections and removing the sample The tubing is cut longitudinally on a milling machine or with a pointed scraping tool, whereupon strips of thin sheet metal are pushed through the slot and the sample This method was first suggested and has been used extensively by **Piggot (725).** It has the advantage that samples of soft or cohesionless soils are continuously supported and remain in the sliced tubing, but there is more disturbance at the surface of the cut and greater development of shrinkage cracks, and the final trimming is more difficult than when the sample is cut into short sections and removed from the tubing before slicing

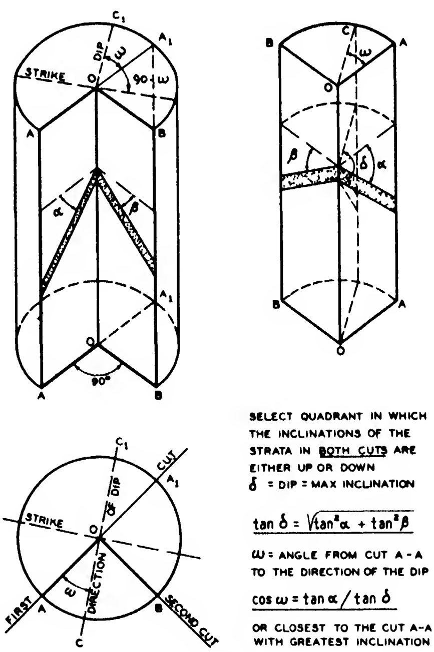
Direction of cut and dip.- All sections of a sample which are to be sliced longitudinally should be oriented in the same manner with respect to the reference line, for example with this line in top position as shown in Fig 348 and 349 When the sections are not oriented alike, the slices will show the stratifications with inclination in different directions and under different angles of inclination, Fig 350



NOTE IT IS ASSUMED THAT THE DIAMETER THROUGH THE REFERENCE LINE IS THE STRIKE OF THE FORMATION

RELATION OF CUT AND DIP OF STRATA

FIG 350



DETERMINATION OF DIP AND STRIKE

FIG 351

The sample should preferably be sliced in the direction of the dip or perpendicular to the strike of the strata; this direction can often be determined by examination of the surface of the sample or cross-sectional slices When the strike and dip cannot be determined in this manner, they can be computed by measuring the inclination of the strata in two cuts perpendicular to each other as shown in Fig 351.

16.11 Increasing the Visibility of Stratifications

The soil in a freshly sliced sample often appears to be homogeneous, or the stratifications may barely be discernible The contrast in color between the various soil layers and the visibility of distortions and planes of failure can generally be increased greatly by partial drying and trimming-off the disturbed surface layer of the sliced sample When this method is ineffective, the visibility of structural details can often be increased by brushing and air blasting or by drying and slaking.

Mechanics of partial drying.- During the process of drying, the color of the soil becomes lighter when the water content approaches the shrinkage limit The various soil layers in a sample dry out at different rates, coarse strata and also undisturbed sections reach the shrinkage limit and change to a lighter color earlier than fine-grained and clayey strata or disturbed sections The color contrast therefore increases during drying until it reaches a certain maximum and will then decrease and may practically disappear when the entire sample has been dried beyond the shrinkage limit An increase in color contrast may also be caused by oxidation, and some organic soils seem first to darken and then to become lighter, but the maximum color contrast caused by oxidation may not coincide with that caused by drying.

Procedure in partial drying.- The sliced sample should be placed on a glass or straight plywood plate, which is covered with a folded paper towel or blotting paper to facilitate uniform drying and to reduce warping and formation of shrinkage cracks When the soil is soft and wet, the paper towel should be exchanged from time to time, at least, the sample should be lifted or turned over by the methods shown in Fig 348 and 349 in order to decrease adhesion between sample, paper towel, and plate The time required for drying until the maximum color contrast is reached varies greatly and must be determined by trial A single day may be sufficient for samples of cohesionless or partially saturated soils, and several days may be required when the sample primarily consists of fat clays, depending on the temperature, humidity and air currents in the room The sample should not be exposed to drafts, which will cause one end or side of the sample to dry at a faster rate than the other and thereby produce misleading color differences and even warping and cracking of the sample

The rate of drying does not seem to influence the color contrast materially, but slow drying assures more uniform results and decreases warping, formation of cracks, and the danger that the point of maximum color contrast is passed unobserved. During the night or other periods when the samples are not under observation, it is advisable to cover them with wax paper or Cellophane or to place them in drawers or on shelves in a cabinet or humid room and thereby retard the drying After the samples have reached the point of maximum color contrast, they may be preserved in that state for several days, pending trimming and photographing, by wrapping the individual samples in wax paper or Cellophane

Trimming of sliced samples.- The trimming of a moist sample will disturb

the soil for a short distance on both sides of the cut, and this disturbance will obscure structural details even after the sample is partially dried The disturbed surface layer should be removed, but any trimming will cause some disturbance of the new surface However, the disturbance caused by trimming is reduced to a minimum when performed shortly before the shrinkage limit and maximum color contrast are attained Trial trimmings should be made from time to time to determine when the optimum water content is reached and the maximum amount of structural details can be made visible It should be noted that the maximum color contrast at the surface proper often is attained a little later and is retained longer than in the soil a short distance below the surface

The trimming should be made with a very sharp knife without burrs or dents on the edge The blade should be fairly stiff since a flexible blade is difficult to guide and tends to cut into the soil and leave knife marks on the trimmed surface When the sliced samples are to be subjected only to a general examination with the object of checking the soil profile or estimating the condition of the sample, a relatively rough trimming with a straight cobbler's knife, Fig 347-lower right, is sufficient On the other hand, when the samples are to be used for detailed examinations or to be photographed, the trimmed surface should be very smooth, and a preliminary trimming with a fine wire saw, Fig 348-5 and 6 and Fig 349-5, will often facilitate the final trimming The preliminary trimming should be performed after the sliced sample has lost some of its water but before the soil becomes too stiff to be cut with a wire saw

DISCOLORATION CAUSED BY PRESSURE ON SAMPLE

FIG 352-A

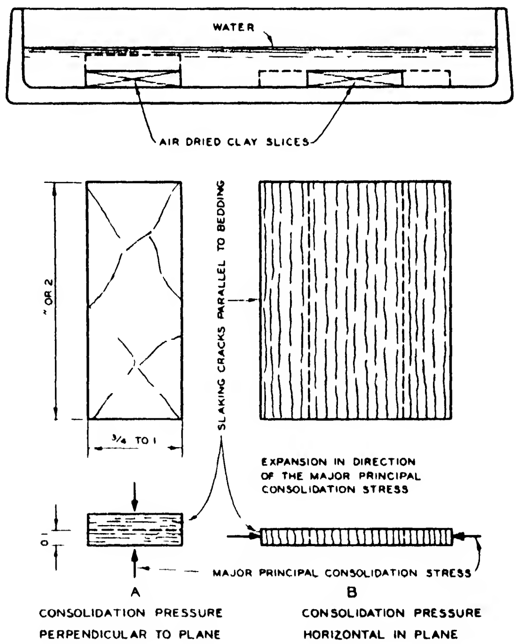
To facilitate the removal of marks left by the rough or preliminary trimming, the knives used in the final trimming should have a gently curved edge or tip, Fig 347-lower left It is not necessary that the trimmed surface be absolutely plane, but it should be smooth and without knife marks, which in photographs often are difficult to distinguish from actual disturbance of the soil The color of the finished surfact may vary a little with the direction of the trimming, in which case the entire sliced sample should be trimmed in a single direction Excessive pressure during the rough or preliminary trimming will disturb the underlying soil and produce areas or streaks with darker than normal color in the partially dried and trimmed sample During the slicing of the sample shown in Fig 352A, a sand grain produced a shallow groove, and a cross made on the Cellophane wrapping made a barely discernible impression on the soil surface The resulting disturbances are visible even though the sample was trimmed to a depth of about 1/16 in below the disturbed surface

Retouching and remoistening.- When a particular stratum or part of the sample

has assumed too light a color on account of uneven or excessive drying, it may be darkened by slow and careful addition of water, applied by means of a camel's-hair brush The brush should not be too wet, since addition of too much water in a single application may cause slaking and require re-trimming of the surface of the sample.

The color contrast of an entire sample, which has become too dry, may be restored by wrapping the sample in a moist paper towel and then in wax paper or Cellophane The paper towel should be moistened or exchanged from time to time, but excessive slaking may take place if the towel is too wet and water is added at too rapid a rate After sufficient water has been absorbed, the sample is dried slowly and trimmed again, since the original surface usually is partially disturbed on account of handling and slaking

Brushing and air-blasting.- Some cohesionless soils show only very faint stratifications, and the color contrast is not increased materially by partial drying. The stratifications and eventual planes of failure can often be emphasized by a low relief, obtained by careful brushing with a soft brush or by a very light air-blast in a direction parallel to the stratifications or planes of failure This operation should be performed after partial but not complete drying of the sliced sample, and trial brushing or air-blasting should be performed from time to time to determine the state of drying at which the best results are obtained In photographing the sample the visibility of the relief is increased by shadow effects, produced by low incidence lighting



DETERMINATION OF PREFERRED ORIENTATION OF CLAY PARTICLES BY DRYING AND SLAKING

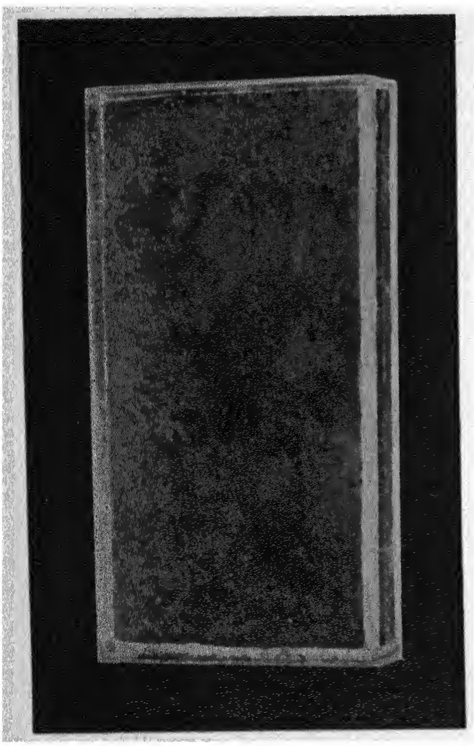
FIG 352-B

Drying and slaking.- Although the majority of sedimentary, cohesive soils have stratifications which can be made visible by partial drying and trimming, apparently uniform strata are occasionally encountered Even such strata have bedding planes or a preferred orientation of the flaky clay particles The direction of this orientation can generally be determined by drying and slaking, **Hvorslev (939)** A thin slice, not larger than 1 by 2 in , is cut out of the sample, completely air-dried, and then trimmed or ground to a thickness of about 0 1 in This slice is placed in a tray and sprayed or barely covered with water The cracks formed by slaking will be parallel to the preferred orientation of the clay particles, which usually is perpendicular to the direction of the major principal stress during consolidation of the deposit, and a conspicuous expansion perpendicular to the cracks or in direction of the major principal stress will take place, **Fig. 352B.**

Even a remolded and re-consolidated clay, upon drying and slaking, will show such a preferred orientation of the clay particles

16.12 Preservation and Photographing of Sliced Samples

Rock cores of small diameter are usually retained in their compartmented boxes for future reference, and small representative soil samples in glass jars are seldom discarded before the entire investigation or project is completed On the other hand, undisturbed soil samples are generally discarded once they have been removed from their paraffin covers or sealed containers and examined, and after representative sections have been selected for testing However, in many cases it is desirable to retain a tangible or visual and readily available record of the soil profile by preserving sliced sections of selected samples or by photographing sliced and partially dried samples and/or test specimens



WATERWAYS EXPERIMENT STATION - CORPS OF ENGINEERS

SLICED SAMPLE OF CLAY IN CASTING PLASTIC

FIG 352-C

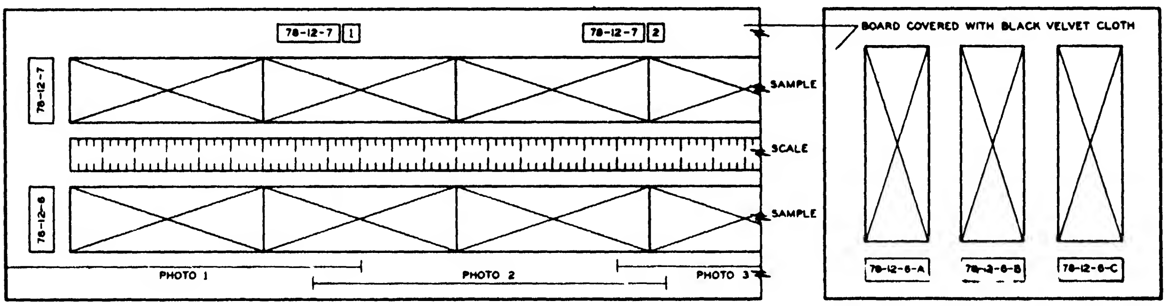
Preservation of sliced samples.- Sliced samples of soils with considerable cohesion can be stored in their completely dried state without special preservation, but they have little value since they neither represent the soil in its natural state nor show the soil structure and stratifications clearly Dry samples of cohesionless soil may be preserved by impregnation with dissolved clear resins, for example vinylite resin, and/or by encasing them in clear plastics as described by **Berger and Muckenhirn** (*) Sliced samples which are partially dried and trimmed at maximum color contrast may also be preserved by encasing them in clear plastics, but a much cheaper, more convenient, and nearly equally clear record can be obtained by photographing the samples

Sliced samples preserved in their natural state or water content form a valuable adjunct to photographs of partially dried and trimmed samples Preliminary experiments on preservation of sliced samples at their natural water content were performed by the **New Orleans District** and are being extended by the **Waterways Experiment Station,** Corps of Engineers. The first method tried consisted in placing the sample between two plates of Plexiglas, which are subjected to pressure while the space along the edges

(*) **Berger and Muckenhirn,** Soil Profiles Embedded in Transparent Plastics, Proceedings Soil Science Society of America, 1946, Vol 11, p 484

is filled with a sealing compound and covered with tape or with thin strips of Plexiglas, cemented to the top and bottom plates Some difficulties have been encountered in obtaining airtight sealing and in avoiding entrapment of air and development of fungus between the Plexiglas and the sample It is probable that better results can be obtained by encasing the sliced samples in transparent, colorless plastics A liquid casting plastic, sold under the trade name of Castolite, has been used in recent experiments, and satisfactory results have been obtained in several cases, Fig 352C However, difficulties have also been encountered, consisting in entrapment of air or development of gas or vapor bubbles and in local discolorations These difficulties can undoubtedly be eliminated by further experimentation and improvement in the casting technique

General procedure in photographing sliced samples.- The samples to be photographed are placed on a background board, Fig 353, resting directly on the



A- SLICED SECTIONS JOINED BEFORE PHOTOGRAPHING   B - SECTIONS JOINED AFTER PHOTOGRAPHING

ARRANGEMENT OF SLICED SAMPLES FOR PHOTOGRAPHING

FIG. 353

floor or on a low bench so that the camera will be at a convenient height The camera is mounted vertically and very rigidly since time exposures are required When photographing sample sections of equal size or diameter, the position of the camera needs seldom be changed, and a simple improvised mounting, as shown in Fig. 354, is satisfactory, but a rigid column with a sliding clamp and bracket for mounting the camera is more convenient when various reductions are used and samples of different sizes are to be photographed

The disturbing effect of shadows can be avoided by covering the background board with black paper or, preferably, black velvet cloth When the sample is dark and a white background is desired, the sample may be placed on a frosted glass plate with or without a sheet of semi-transparent, white paper, which is lighted from below in a degree just sufficient to counteract the shadows caused by the main lights above the sample

The individual sections of a long sample may be joined on the board before photographing, Fig 353A, and two or three strings of samples can often be photographed at the same time, Fig 107B The board with the samples is moved forward in steps and in such a manner that slightly overlapping photographs are obtained. Another and often more convenient method consists in photographing the individual sample sections in parallel arrangement, Fig 353B, and joining the prints of these sections when a single composite photograph of an entire sample is desired A scale is often photographed with the samples, but when a photograph with such a scale is used to determine the soil profile or measure the thickness of individual strata, the shrinkage of the samples during the partial drying must be taken into consideration The original net length of the sample is known, and it is in many cases preferable to draw a scale on the finished single or composite photograph by means of which the original dimensions of the sample can be measured directly

The surface of the sliced sample and the film or back of the camera must be parallel and careful checking with a spirit level is advisable, since a deviation causes the sample width to vary in the photograph, and even a slight difference in width is very conspicuous when individual sections are joined to form a composite photograph

The sample should be evenly lighted, and it is best to use two photoflood lights, symmetrically placed with respect to the sample, Fig 354 Lighting at right

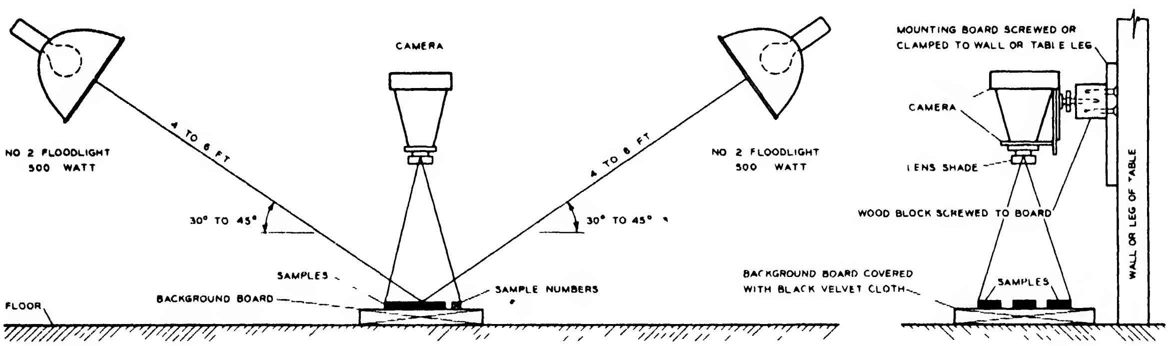


FIG 354 - PHOTOGRAPHING OF SLICED SAMPLES

angle to the stratifications or along the axis of the sample usually produces the best results When there is little color contrast in the sample and the stratifications appear in low relief after brushing or air-blasting, the angle of incidence of the lighting should be small in order to emphasize the relief by its shadows. In such a case a single flood light is used, and it is placed 6 to 10 ft from the sample to decrease the difference in intensity of light on the nearest and farthest ends of the sample

Camera and film.- A sturdy hand camera with a good lens, double extension bellows, ground glass for focusing, and adapters for 9 by 12 cm, 4 by 5 in., or 3-1/4 by 4-1/4 in. sheet film is satisfactory and convenient for photographing soil samples. A Polaroid filter is useful in reducing glare from a sample with a very smooth surface The color contrast can often be increased by means of green or blue filters, whereas

the contrast can be decreased and better texture and detail in the photograph obtained by use of yellow to orange filters when the sample has strong and contrasting orange to reddish colors

Straight or Orthochromatic Process film usually gives good results when the sample has little to medium color contrast, but Contrast Process film often causes loss of details in the shadows and halftones Commercial or Commercial Orthochromatic film is satisfactory for photographing samples with medium contrast, whereas medium soft Panchromatic film should be used when the sample has strong and contrasting colors Very striking photographs can be obtained by use of color film, but such film and especially reproductions in color are relatively expensive for general use

Exposure, development, and printing.- An exposure meter will give an indication of the required time of exposure, but the short distance to the sample and consequent extension of lens and bellows, the degree of contrast in the sample, and the type of developer to be used should be taken into consideration in addition to the speed rating of the film Trial exposures on various types of film are usually required until sufficient experience is gained

A clean working, medium contrast developer or the developers recommended for particular film should be used When sections of a long sample are photographed on several film, it is advisable to develop these film at the same time and in a tank in order to obtain negatives of uniform density and contrast and thereby facilitate the making of uniform prints, suitable for assembly in a composite photograph Best results are obtained with negatives of such density and contrast that paper of normal contrast can be used in printing By use of contrast film, developer, and paper, singly or combined, it is possible to obtain prints with much greater color contrast than that in the partially dried and trimmed sample, and features which are barely discernible in the sample may thereby be displayed prominently in the photographic print However, excessive increase of the color contrast during photographing will often cause loss of some of the finer details in either highlights or shadows.

Advantages and uses of photographs of sliced samples.- Photographs of partially dried and trimmed samples are relatively inexpensive, they are easy to handle and file, they can be reproduced for use in reports and publications; and they provide a pictorial record of the soil profile which often shows more details of stratifications and soil structure than can be seen in the sliced sample in its natural or completely dried state A complete pictorial record of the soil profile, obtained by slicing and photographing all the samples from one or two representative borings, is often of great value, especially in case of large projects and since the undisturbed samples usually are discarded after examination and testing or are preserved in such a manner that they cannot be inspected easily and frequently

In many cases it will also be found advantageous to slice and photograph soil specimens which have been used for consolidation, compression, direct shear, or

triaxial tests, or to slice and photograph sections of the sample immediately above and/or below the test specimen Such photographs, attached to the test report, materially assist readers of the report in forming a conception of the soil type and structure and in estimating the condition of the test specimen and the value of the test results

16.13 Control and Consistency Tests on Samples

Simple and reliable control tests, by means of which it can be determined whether any changes in the physical properties of the soil take place before and during the actual sampling operation, have not yet been developed. The object of the tests discussed in this section is to determine the extent of possible changes in volume, water content, and structural strength of the sample in the period between sealing the sample in the field and its examination and testing in the laboratory Some of these tests furnish in addition preliminary data on the density and consistency of the soil

Changes in volume.- The simplest of all control tests consists in measuring the net length of the sample after it has been trimmed for sealing and in checking this length in the laboratory after the sealing plugs or caps have been removed Obviously, it is not necessary to measure the net length in the field when the sample is trimmed flush with both ends of a liner section or short sampling tube Assuming that there is no annular clearance between the sample and its container, changes in the net length reflect changes in volume which may be caused by vibrations, drying, absorption of water, or by release and expansion of gases entrapped in the pores or dissolved in the pore water Knowledge of the net length of a sample preserved in a long sampling tube or liner also facilitates the division of the tubing into sections of appropriate lengths before removing the sealing plugs and pushing the sample out

Changes in water content.- Weighing the sample in the field and checking the weight in the laboratory provide data for determination of changes in water content. The sample is weighed with its container after it has been trimmed and either before or after sealing. Weighing after sealing has the advantage that any loss in weight can be determined without removing the sealing plugs or the caps and tape. Before weighing, any moisture on the container should be wiped off, and the container and sealing should be inspected for corrosion and damage causing changes in the original weight

The sample should be weighed before sealing when the sealing plug is held in place by a plug of plaster of Paris, since the latter may lose or absorb considerable amounts of water, depending on the consistency of the plaster of Paris mortar and the humidity of the air in which the sample is stored; see Table 13 -- Test 12. Weighing before sealing has the advantage that it permits computation of the unit weight of the soil when the diameter and net length of the sample and the weight of the container are known For this reason, the weighing is performed before sealing when the sample is trimmed flush with the ends of short sampling tubes or liner

sections of constant length, volume, and weight

Changes in structural strength.- The shearing resistance of the soil is generally affected by changes in volume and/or water content Even when the latter remains constant, the shearing resistance may be changed by vibrations and other physical disturbances, by thixotropic changes, and by chemical changes caused by electrolysis, corrosion, or oxidation Appreciable changes in shearing resistance may be detected by making cone penetration tests, squeeze tests, or unconfined compression tests on the ends of a sample or on small test specimens cut from the sample before it is sealed, and then repeating these tests when the seals have been removed in the laboratory

Published results of structural control tests usually indicate a loss in shearing strength during shipment and storage of the sample However, it is possible that the control tests in the laboratory may have been performed too close to those made in the field and that the loss in strength in some cases is apparent rather than real. Whenever a cone penetration test is made or a test specimen is taken with a small punch or sampling tube, the surrounding soil is partially disturbed, and laboratory control tests on this disturbed soil will usually indicate a loss in strength

Systematic experiments to determine the extent of the disturbance caused by making a control test have not yet been made However, it is tentatively suggested that the distance from center to center of 1-cm deep cone penetration tests or 5/8-in round test specimens for squeeze or compression tests should not be less than 1-1/2 in , and that the distance from the center of the test area to the circumference of the sample should be at least 3/4 in If these requirements are substantiated, reliable control tests cannot be made on an area less than 3 in in diameter, unless the tests are made in the center of the sample and the soil is so uniform that the laboratory test can be made satisfactorily on soil below that disturbed by the field test When the sample is preserved in sectionalized liners of small diameter, it would also be possible to make the field control test on soil from the bottom of one section and the laboratory test on soil from the top of an adjoining section

Squeeze tests.- The desirability of making structural control tests on soil samples was first suggested by **Burmister (602, 603)**, who developed a modified form of the squeeze test first proposed by **Jurgenson (941)**. The control testing equipment consists of a small punch or sampler and an apparatus for performing the squeeze test, Fig 355 The surface of the sample is planed off and the punch pushed about 1/2 in into the soil, whereupon a knife is inserted below the punch to cut the sample free. The punch is withdrawn and the plunger pushed down until it engages the first bayonet lock The protruding soil is trimmed off, leaving a test specimen with a height of 1 cm and a diameter of 5/8 in or 2 cm^2 in area

The punch with the soil is placed in the testing apparatus and locked with the cutting edge flush with the underside of the upper plate The test specimen is then pushed out by forcing the plunger down and engaging it in the second bayonet

lock. The upper plate with the test specimen is lined up over the pins in the lower plate, and pressure is exerted on the loading springs until the touch knobs can be felt through the holes in the springs, which indicates that the total load is 2.0 kg. The springs are adjusted to this load by means of calibration notches. The entire assembly is now turned over, and the diameter of the soil pad, which can be seen through the frosted glass base, is measured For testing stiff soils, the loading springs are calibrated for a total load of 5 0 kg.

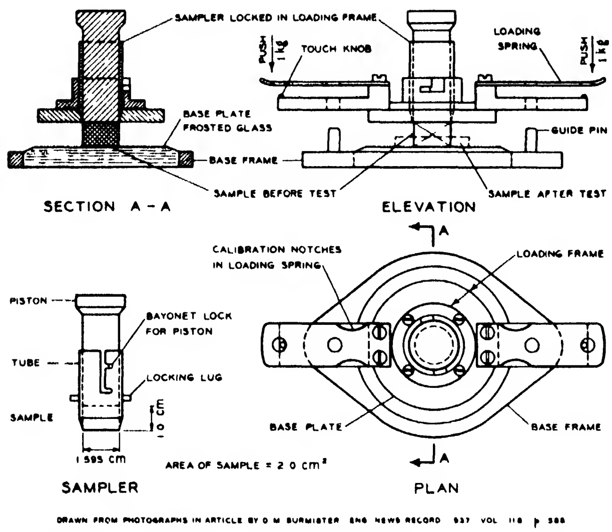


FIG 355 - SQUEEZE TEST APPARATUS BY BURMISTER

The shearing resistance of the soil can be determined from the load on and the diameter of the squeezed soil pad, approximately by theoretical formulas but better by means of experimentally derived graphs (602, 603) However, the shearing resistance determined is not that of the undisturbed soil but of the deformed and partially disturbed soil pad In case the shearing resistance of the soil decreases with increasing deformation after failure, the influence of disturbances during handling, shipment and storage of the sample may be obscured to some extent by disturbance during the squeeze test proper

Cone penetration tests.- Cone penetration tests were developed by the **Geotechnical Commission** of the **Swedish State Railroads** (967) as an easy and quick method for determination of the approximate shearing resistance of cohesive soils In the original method a steel cone with a given weight and top angle is released when its point just touches the soil surface. The penetration of the cone under its own weight and momentum is measured, and the corresponding shearing resistance is determined by means of experimentally derived tables and graphs. Later, engineers in Holland and Denmark replaced the drop cone with a statically loaded cone and measured corresponding penetrations and loads or simply the load required to produce 1-cm penetration of the cone

A simple and practical apparatus of the latter type has been developed by **Godskesen (609, 610).** The original design is shown in Fig 356, but a revised model has a length of only 12 cm The 60° cone of stainless steel is attached to a section of slotted tubing in which a rod with a handle slides The force on the cone is measured by means of two helical compression springs, and the short and stiff inner spring does not come into action before the load exceeds 4 kg, so that two calibration ranges are obtained. The penetration is measured by pushing a small rule into the soil before the test and placing the base of the cone close to the rule during the test The cone is withdrawn when the penetration reaches 1 0 cm, and the

corresponding force is read on the maximum load indicator

The shearing resistance corresponding to load and penetration can be computed by formulas based on theoretical considerations, but more reliable results are obtained by means of experimentally derived formulas and graphs The soil around and below the cone is disturbed as the test progresses, and the equilibrium of load and penetration does not correspond to the shearing resistance of the undisturbed soil but to that of partially disturbed soil The load or penetration will also depend to some extent on the speed with which the cone is pushed into the soil In spite of these shortcomings, the cone penetration test may be used to advantage in many preliminary investigations, and it is easier to perform than either the squeeze test or the unconfined compression test

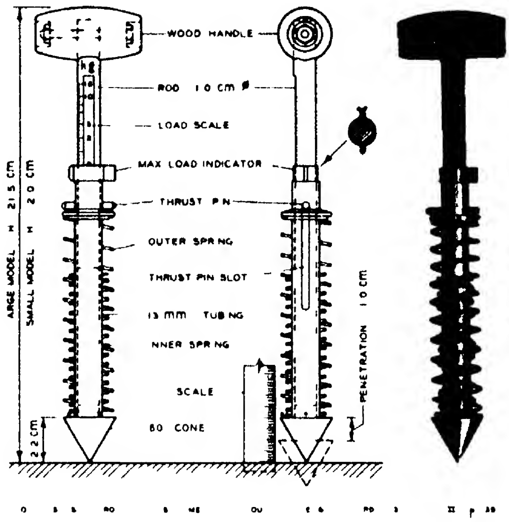


FIG 356 - CONE PENETROMETER BY GODSKESEN

Unconfined compression tests.- A portable compression test apparatus with automatic recording of the stress-strain curve has been developed by **Cooling and Golder (606)**, and a simple arrangement for making rough unconfined compression tests in the field by means of a yoke and a spring balance has been suggested by **Casagrande and Wilson (250)**. In both cases test specimens with a diameter of 1-1/2 in and a length of 3 to 3-1/2 in are specified, and such samples are too large when used solely for control tests, but the above mentioned apparatus and method could be adapted for smaller test specimens

A pocket-size piston sampler and compression test apparatus (*) for obtaining and testing samples only 5/8 in in diameter and 1-1/4 in long are shown in Fig 357 The sampler is identical in design and operation to the 1-in sampler shown in Fig 316 and is also provided with an auxiliary piston rod support, consisting of an annular base plate with two adjustable rods, for use in operating the sampler with stationary piston when taking samples of soft or easily compressible soils

The compression test apparatus consists essentially of a base with a guide frame and a loading unit The latter is a pair of telescoping tubes with two helical compression springs which provide an upper and lower calibration range, since the height of the range spacer inside the lower and weaker spring is so adjusted that the spacer touches the cup between the two springs when the load corresponds to 2 kg per sq cm The movement of the inner tube with respect to the outer tube indicates the load, whereas the movement of the outer tube with respect to the guide frame indicates the deformation of the test specimen Since the latter has constant length

(*) **M. Juul Hvorslev Pocket-Size Piston Samplers and Compression Test Apparatus Second International Conference on Soil Mechanics and Foundation Engineering, Rotterdam, 1948**

and cross-sectional area, the calibration is made to read directly in stress and strain, both referred to the original dimensions of the test specimen

After placing the test specimen centrally on the base and adjusting the stress and strain indicators, the inner tube is pushed slowly down with the fingers of one

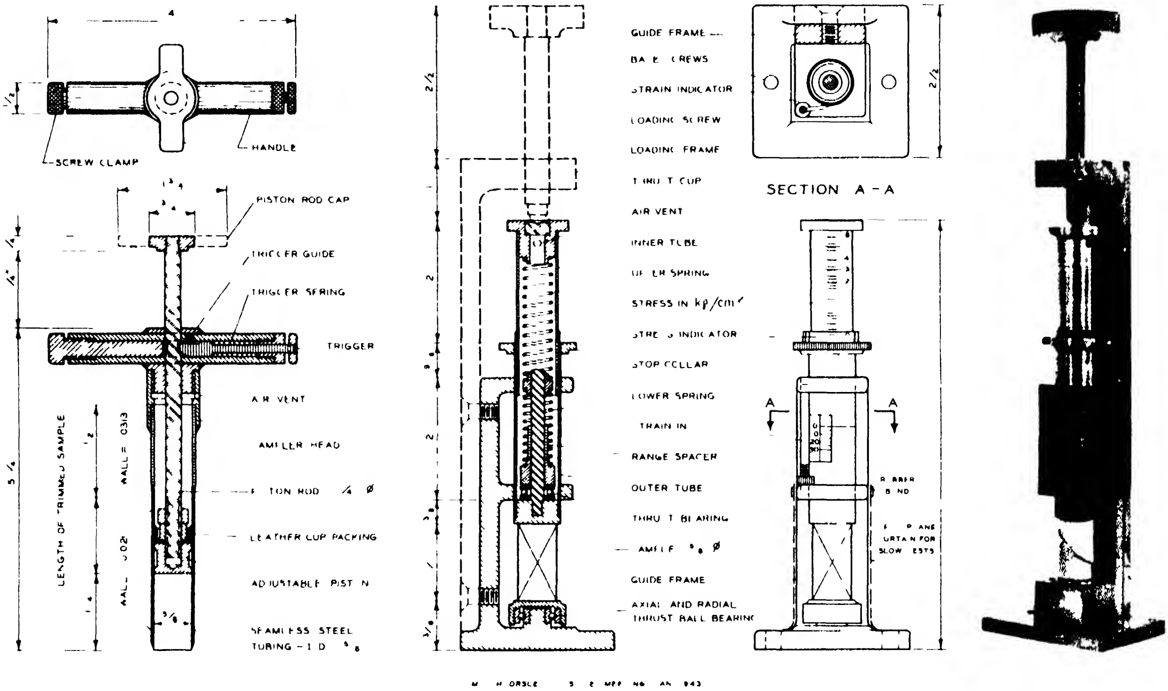


FIG 357 - 5/8 SAMPLER AND COMPRESSION TEST APPARATUS

hand, while with the other hand the outer tube is rotated slightly back and forth to eliminate the influence of friction between the two tubes and between the outer tube and the guide frame Ball bearings in the loading unit and the base facilitate rotation and prevent transfer of torsional moments to the test specimen When cracks or other signs of failure appear in the test specimen, the strain, e, should be noted and the pressure on the inner tube released The slip ring on the inner tube indicates the maximum stress, σ_0, and the corresponding average stress in the deformed test specimen is then $\sigma = \sigma_0(1 - e)$ When the soil fails by gradual plastic deformation, the test is continued until the strain reaches a certain arbitrary value, for example 20 percent

The load may also be applied by means of a loading screw, shown in the photograph of an early model of the apparatus and dotted in the revised design in the center of Fig 357. Use of the loading screw permits performance of slower tests and facilitates observation of corresponding values of the stress and the approximate strain throughout the test Before each reading is taken, the outer tube should be rotated a little to eliminate the influence of friction The plotting of a rough stress-strain curve will furnish a more accurate value of the maximum average stress and also an approximate value of the modulus of deformation

A similar compression test apparatus has been built for testing of samples taken with the 1-in. piston sampler shown in Fig. 316 The larger test specimens permit more accurate determination of the stress-strain curve, but so far only very little difference has been observed in the values of the maximum average stress obtained by the two sizes of test specimens The modulus of deformation as determined by means of the stress-strain curve is usually much more sensitive to disturbance of the soil structure than the maximum average stress and is therefore a better indicator of partial disturbance of the soil during shipment and storage of the sample

These samplers and compression test apparatus are not intended for precision tests and are primarily designed to obtain minimum weight, maximum compactness, and simplicity in construction and operation The use of the samplers for cutting out a test specimen may cause a slight disturbance and decrease in strength of some brittle and soft soils and a slight compaction of partially saturated and relatively loose soils When the compression test apparatus is properly operated, the error in determining the vertical stress will usually not be more than 0 02 kg/cm^2 for small loads and 2 percent for stresses over 1 0 kg/cm^2, but greater errors can be expected when the pressure on the inner tube is not applied centrally and axially and when the influence of friction is not eliminated by rotation of the outer tube.

With exception of soils which fail by gradual plastic deformation, the partial disturbance of the soil during a compression test and at the moment significant observations are made is smaller than during squeeze tests and cone penetration tests The unconfined compression test is therefore more sensitive as a control test, especially when also the stress-strain curve and the modulus of deformation are determined. In addition, the compression test furnishes directly values of a significant physical property, and the constant volume of the test specimens used greatly facilitates determination of the unit weight, water content, void ratio, and degree of saturation of the soil

The compression test apparatus and also the squeeze test and cone penetration test apparatus are intended and used not only for control tests but in general for making preliminary soil tests during field investigations of exposed soil deposits and during laboratory examination of samples Such tests contribute greatly to a more accurate classification of the soil, especially in regard to its strength or consistency

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1. Special Reports and Communications to and by the Committee

No. 100 to 200. Special reports and communications to the Committee containing description and drawings of methods and equipment used in subsurface exploration and sampling of soils Manufacturers' catalogues, unpublished general reports and papers placed at the disposal of the Committee Unpublished progress reports and other reports by Members of the Committee and its Research Engineers (Many reprints of published papers were also received, but these have been listed in their appropriate Sections)

2. Handbooks, Textbooks, and Manuals

No. 200 to 300. Handbooks, textbooks, and manuals dealing with or containing chapters on subsurface exploration for civil engineering purposes and classification of soils, also a few books dealing with subsurface exploration for other than civil engineering purposes

3. Subsurface Exploration in General

No. 300 to 400. Papers, pamphlets, and engineering standards whose main subject is the general principles and methods of subsurface exploration for civil engineering purposes Test pits and borings Description of subsurface exploration of particular projects. (For geophysical methods, sampling, and minor field tests see Sections 4, 5, and 6)

4. Geophysical Methods of Subsurface Exploration

No. 400 to 500. Papers dealing with the application of geophysical methods in subsurface explorations for civil engineering purposes (See also Section 2)

5. Sampling of Soil and Rock

No. 500 to 600. Papers pertaining mainly to methods and equipment for obtaining samples of soil and rock, including papers on core boring in rock (See also Section 3)

6. Minor Field Tests

No. 600 to 700. Papers describing construction and use of portable equipment for field classification, consistency, and control tests on samples or the soil in situ, such as unit weight determinations, penetration, squeeze, and unconfined compression tests. Methods and equipment for determination of ground-water levels and pressures. (The papers listed under Ref. No. 601, 615, and 619 should have been placed in Section 3. Major field tests, such as large surface or pile loading tests, pumping tests, and earth pressure tests are not considered in this bibliography.)

7. Subsurface Exploration for Other than Civil Engineering Purposes

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8. Classification of Soils for Engineering Purposes

No. 800 to 900. Papers dealing in toto or in part with identification and classification of soils for civil engineering purposes (See also Sections 2, 3, and 9)

9. General References

No. 900 to 1000. Papers in which methods and equipment for subsurface exploration have been described but are not the main subject Papers dealing with physical properties of soils and the influence of the disturbance of samples Field and laboratory testing requirements to be considered in sampling of soils

10. Recent Additions

The preceding sections of the bibliography were completed early in 1947, and additions or substitutions have been made only when this could be accomplished without changing the established reference numbers Communications and reports received by the Committee and papers published and/or added to the bibliography during the last year are assembled in this section These reports and papers are classified in subsections corresponding to the main sections of the bibliography, and the reference numbers given the papers in these subsections are a continuation of those used in the main sections.

Abbreviations

The abbreviations used in references to publications in the English language are confined to those which may be considered as being more or less standard. With a few exceptions, abbreviations are not used in references to publications in other languages

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APPENDIX

APPENDIX

CONTENTS

APPENDIX

The purposes of this appendix are to call attention to typographical errors and desirable minor revisions of the original report, to extend the scope of some sections, and to present brief reviews of information on new developments which has been published or made available during the period between the preliminary and the final printing of the report.

A-1 Minor Revisions and Additions

Typographical errors.- The following errors have been found to date:

Page 1, Line 21	Add "may be" before "obtained."
Page 17, Line 4	Change "still strata" to "stiff strata."
Page 17, Line 33	Change "Committee" to "Society."
Page 24, Line 4	Change "Society of" to "Society for."
Page 37, Line 6	Change "Committee" to "Commission."
Page 55, Fig. 31	Change "Keystone" to "Cyclone."
Page 68, Line 1.	Change "Prentiss" to "Prentis."
Page 116, Fig. 108-A	Change "outside" to "inside."
Page 158, Line 28	Change "core hole" to "bore hole."
Page 231, Line 19:	Change "drill rods" to "casing."
Page 233, Fig. 174	Change taper "1 in 5" to "1 in 6."
Page 272, Line 16·	Change "Stockstad" to "Stokstad."
Page 287, Line 3·	Table mentioned replaced with other data.
Page 353, Line 17:	Change "Heitdecker" to "Heithecker."

Section 3.3, page 74.- Complete equalization of the hydrostatic pressures in the soil and in a boring or observation well cannot be attained when the ground-water pressure fluctuates, and there may be considerable difference between the observed and actual pressures when the rate of change in ground-water pressure is large or the period of fluctuation is small compared with the time-lag. Details concerning determination and influence of the hydrostatic time-lag are contained in a recent paper by the writer (A-17). It is emphasized that the time-lags listed in Table 4 are theoretical values, computed under the assumptions specified below the table. Because of many other disturbing influences, there may be considerable difference between the theoretical and actual values of these time-lags and the main purpose of the table is to call attention to the importance of the time-lag and to the relative

responsiveness of the various methods and devices for measurement of ground-water levels and pressures.

Section 4.9, page 118.- It is stated that hammering practically eliminates entrance of excess soil, even when the area ratio of the sampler is large. This conclusion is based on sampling experiments close to the ground surface. However, the possibility that excess soil may enter the sampler increases with increasing depth of the bore hole, and this possibility may not be eliminated by use of hammering after moderate depths are attained. During the use of a Burkhardt pile boring sampler, Fig. 58, with an area ratio of about 25 percent and advanced by hammering, **Furrer (A-15)** observed up to 20 percent excess entrance of soil.

Section 4.15, Table 7 and page 140.- In view of recent developments utilizing compressed air or drilling fluid for sampling of saturated sand (Section A-4), freezing of the bottom of the sample can no longer be considered the best available method for preventing loss of undisturbed samples of sand and silt. This note applies also to statements on page 175.

Section 4.19, page 156.- The chilled steel shot used in shot core boring is known under the trade name "Calyxite," see Fig. 274-B, page 334. Pre-crushed shot or angular steel grit is used for shot core boring in relatively soft rock.

Section 9.8, page 249.- In sampling of soft or loose soils, the **Moran and Proctor** sampler has been replaced with thin-wall, open or piston samplers, but it is still used in sampling of hard cohesive soils and dense coarse-grained soils where hammering is required to force the sampler into the material.

Section 13.5, page 341.- Solid diamond drilling bits have recently been used very successfully for blast hole drilling in a 35-ft-diameter spillway tunnel of the Hungry Horse Project in Montana, **Wheeler (A-45)**. These diamond bits made it possible to drill straight, 60-ft-deep holes parallel to the axis and close to the periphery of the tunnel, whereby the operations were accelerated and the amount of overbreak decreased.

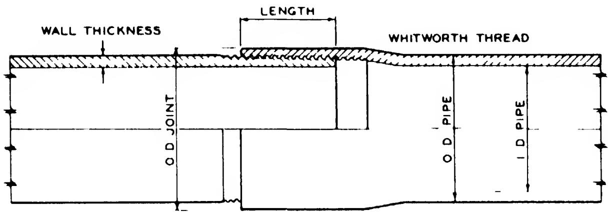
Section 14.7, page 361.- Bore hole surveys by orientation of the drill pipe are often preferred for shallow holes and are required when a drift-direction indicator with gyroscopic compass is not available and surveys must be made within a cased hole or close to lost tools or magnetic deposits.

A-2 Tubing for Casing, Drill Rods, and Samplers

The tables and figures in Chapter 8 are in most cases based on data found in catalogues and bulletins issued in 1945 and 1946. A comparison with the latest available catalogues shows that the principal dimensions of pipe and tubing have not been changed; but the form of the figures and tables has been revised in some instances and, as indicated in the following paragraphs, some sizes and types of pipe have been eliminated and others added.

Standard and Line Pipe.- Fig. 161, only butt-welded, but neither lap-welded nor Seamless, Standard Pipe is available in sizes smaller than 2-in. pipe. Fig. 162, sizes 15 and 17 of A.P.I. Line Pipe are no longer available.

Special casing and Drill Pipe.- Fig. 164, sizes 15 and 17 of Seamless Drive Pipe have been eliminated. The seamless casing with flush couplings, Fig. 168, is no longer listed in the manufacturer's catalogue.



Size nominal	Weight per foot plain ends	Casing			Number of threads per inch	Joint	
		Wall thickness	Diameters			Length	Outside diameter
			Outside	Inside			
Ins	Lbs	Ins	Ins	Ins		Ins	Ins
2	5 15	240	2 250	1 770	10	2 200	2 608
2¼	5 79	240	2 500	2 020	10	2 200	2 858
2½	6 43	240	2 750	2 270	10	2 200	3 108
2¾	7 34	250	3 000	2 500	10	2 450	3 378
3	8 01	250	3 250	2 750	10	2 450	3 628
3¼	8 68	250	3 500	3 000	10	2 450	3 878
3½	9 69	260	3 750	3 230	10	2 700	4 148
3¾	10 39	260	4 000	3 480	10	2 700	4 398
4	11 08	260	4 250	3 730	10	2 950	4 648
4¼	11 77	260	4 500	3 980	10	2 950	4 898
4½	12 47	260	4 750	4 230	10	3 200	5 148
4¾	13 16	260	5 000	4 480	10	3 200	5 398
5	13 86	260	5 250	4 730	10	3 700	5 648
5 3/16	15 08	270	5 500	4 960	10	3 700	5 918
5⅝	16 52	270	6 000	5 460	10	3 950	6 418
6¼	18 33	270	6 625	6 085	10	3 950	7 043
6⅝	19 41	270	7 000	6 460	10	4 200	7 418
7¼	21 21	270	7 625	7 085	10	4 200	8 043
7⅝	23 09	280	8 000	7 440	10	4 450	8 438
8¼	24 96	280	8 625	8 065	10	4 450	9 063
8⅝	26 98	290	9 000	8 420	10	4 700	9 458
9⅝	30 07	290	10 000	9 420	8	4 625	10 428
10⅝	35 39	310	11 000	10 380	8	4 875	11 468
11⅝	38 70	310	12 000	11 380	8	4 875	12 468
12½	47 29	350	13 000	12 300	8	5 125	13 548
13½	51 02	350	14 000	13 300	8	5 125	14 548
14½	59 33	380	15 000	14 240	8	5 625	15 608
15½	63 39	380	16 000	15 240	8	5 625	16 608
18 D	81 97	437	18 000	17 126	8	5 625	18 722
20 D	91 31	437	20 000	19 126	8	5 625	20 722

NATIONAL TUBE CO - OIL COUNTRY TUBULAR PRODUCTS-1948

NATIONAL SEAMLESS INSERTED JOINT CASING

EXPORT STANDARD

FIG A-1

JONES & LAUGHLIN STEEL CORP.

TOOL JOINT WITH WEAR BANDS

FIG A-2

Casing with inserted joints was shown in earlier General Catalogues of the **National Tube Company** but not in those issued since 1945. However, Export Standard, Seamless Inserted Joint Casing is listed in the recent catalogue of Oil **Country** Tubular **Products** (A-26), and the principal dimensions are reproduced in Fig. A-1 since this type of casing apparently still is used to a considerable extent outside the United States.

The Integral Joint Drill Pipe, manufactured by **Jones & Laughlin Steel Corporation (A-18)** and shown in Fig. 174, has joints formed from forged upsets of the pipe. Since the outside diameter of these joints is greater than that of the pipe proper, the joints are subject to considerable grinding against the walls of the bore hole. In order to reduce the consequent abrasion, the box ends of the joints are now provided with several high-alloy wear bands, Fig. A-2.

External flush drill rods or drill pipe is often subject to irregular wear by grinding against the walls of the bore hole or casing. By using double pin or double box couplings with a diameter slightly greater than that of the pipe, the abrasion may be confined to the coupling, and the cost of repairs or replacements is thereby reduced.

Plastic coated steel tubing.- As mentioned on pages 125 and 247, it is highly desirable that thin-wall sampling tubes and liners be provided with a smooth, hard, and corrosion resistant coating, and such a coating becomes a necessity when undisturbed soil samples are to be preserved in steel tubing for more than a few days. Complete removal of rust and factory grease before lacquering is essential but often difficult and relatively expensive, and coating of the tubing can undoubtedly be performed cheaper and better at the mill. Thin-wall steel tubing with a thin, corrosion resistant, plastic type coating has recently been developed by the **Jones & Laughlin** Steel Corporation (A-18). The current product, called "Perma-Tube," is electric welded tubing with a slight burr along the inside welded seam. Tubing with such a coating but without burrs can undoubtedly be used to advantage for thin-wall samplers and liners.

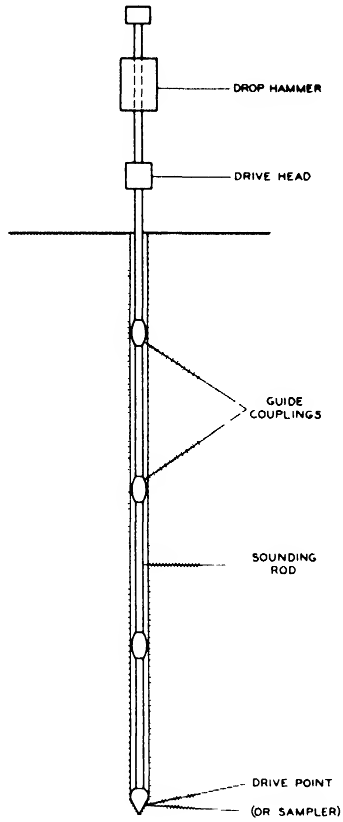
Transparent plastic tubing.- Advantages and limitations of liners of transparent plastic materials are discussed briefly on page 125. Split liners formed of celluloid strips have been used in a few cases, Fig. 255 and Copeland (508). Solid-wall liners of a more water resistant material would be preferable, but until recently seamless plastic tubing with the required diameters and wall thicknesses has not been available. According to Stetson (A-35), transparent plastic tubing with a wall thickness of 1/16 in., called "Tulox TT," is now manufactured by **Extruded Plastics Inc.** of Norwalk, Connecticut, and has been used with satisfactory results as liners for the free-fall sampler shown in Fig. 257.

A-3 Geophysical and Sounding Methods

Use of the electrical resistivity method.- As an example of the use of the electrical resistivity method of subsurface exploration, reference is made to recent papers by Perret (438 and especially A-27) which contain detailed discussions of both the theory and practical application of the resistivity method and of the results obtained in extensive subsurface explorations by the **Waterways Experiment Station.** The purpose of the explorations was to determine, along a 40-mile-long section of levee, depths to the boundary between porous deposits of Recent alluvium and the underlying impervious clays of Tertiary age. Two methods of evaluating the field

data are discussed, and the results are correlated with or checked by means of borings, spaced 5,000 ft apart. For depths up to 100 ft, it was found that the depths to the Tertiary deposits determined by the electrical resistivity method usually were correct within 3 percent, but resistivity depths to intermediate strata in the Recent alluvium were subject to greater errors. The seismic refraction method could not be used in the above mentioned case, since the wave velocity in the Tertiary clays was smaller than in the overlying deposits. In other cases the seismic refraction method may be preferable to the electrical resistivity method, and a critical comparison of the two methods is contained in previous reports by the **Waterways Experiment Station** (A-40 and A-41).

Drive rod for sounding and sampling.- A simple sounding rod with guide couplings for determining the dynamic point resistance or obtaining representative samples has recently been developed by **Couard** (A-10) and is shown in Fig. A-3. The diameter of the rod is considerably smaller than that of the conical drive point, and the relatively short sections of the rod are joined by oblong couplings, which have a diameter only slightly smaller than that of the drive point and serve to prevent buckling of the rod. This arrangement practically eliminates skin friction and permits use of a drive point and a rod of very small dimensions, but it cannot be used in stony ground or when the soil is so soft that the hole does not remain open. The assembly is hand-operated and forced into the soil by blows of a light hammer with a regulated, constant height of fall. When representative samples are desired of certain strata, the drive point is replaced with a small drive sampler. The weight of the entire equipment is about 50 kg.



A COUARD LE GENIE CIVIL DEC 1948 P 473

SOUNDING ROD WITH GUIDES

FIG A-3

Rotary sounding method.- Recent improvements of static sounding rods with sleeve pipe, described in Section 2.8, include a hollow cone point which prevents entrance of soil into the space between the cone and the sleeve pipe, **Plantema** (368) and **Vermeiden** (372), and arrangements for a continuous instead of stepwise advance of the sounding rod and recording of the point resistance, **Plantema** (368). Because of influence of the skin friction, static sounding rods for deep penetration require special and very heavy jacking equipment, and the depth which can be reached in firm or cohesionless soils is generally less than 100 ft. In efforts to develop a method which would permit sounding to depths of 150 to 200 ft by use of available drilling equipment, the **Waterways Experiment Station** first attempted to eliminate the skin friction by means of drilling fluid and jetting of the sleeve pipe. It appeared that the

desired results could not be obtained solely by means of jetting, but other preliminary experiments indicated that a combination of rotary drilling and sounding possibly might be successful. Rotary sounding equipment, as designed by the writer and shown in Fig. A-4, has been built, and field tests are in progress during which alternative designs of the cone point and simple swivel arrangements with pumping directly into the cone rod are to be investigated.

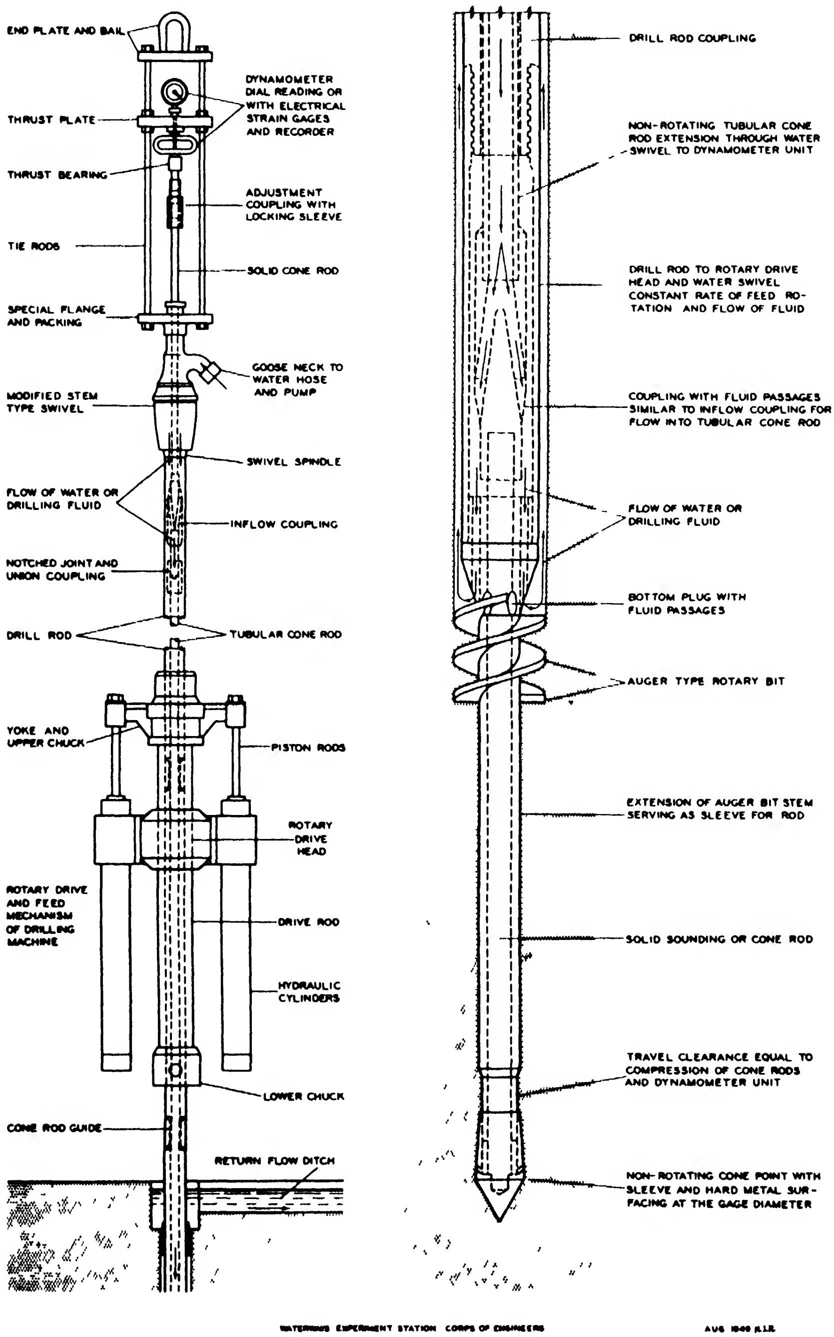
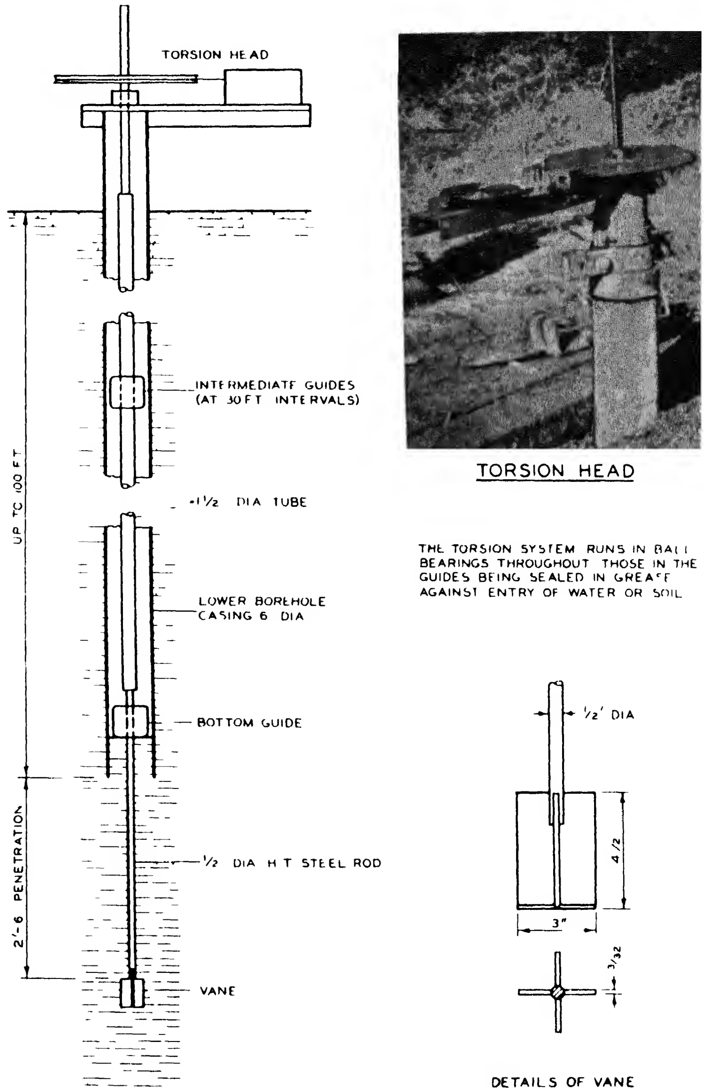


FIG A-4 - ROTARY SOUNDING METHOD

The drill rod or sleeve pipe has a spiral auger bit, and the sounding cone fits over the end of an extension of the bit stem which is of sufficient length to place the cone point below the zone of disturbance created by the bit and rotary drilling. The cone is attached to an interior rod which extends up through the drill rod, is supported by guides at required intervals, and passes through the water swivel to a force measuring or recording arrangement. The latter is attached to the water swivel and thereby to the drill rod. Recording of the force on the cone point requires but very little vertical movement of this rod with respect to the drill rod. The latter is rotated and forced into

the soil by means of a drilling rig of the type shown in Fig. 37. Water or drilling fluid is pumped through the swivel, the hollow cone rod, and the jet openings above the bit. Clearance created by the bit and use of drilling fluid in soft or cohesionless soils will tend to prevent their closing-in on the drill rod and establishing skin friction. Since rotation of the cone rod is prevented, longitudinal friction between it and the rotating drill rod is almost eliminated, and corrections for weight of the cone rod and influence of fluid pressure are determined during calibration.

A constant speed of rotation and feed of the drill rod and a constant rate of circulation of water or drilling fluid will be used in an effort to stabilize the influence of these factors. Furthermore, the cone point is always a constant distance below the bit or bottom of the bore hole, and the force on the cone is recorded continuously as the drill rod advances, the operations being interrupted only by re-setting of the hydraulic cylinders or addition of new rods. By thus standardizing the conditions under which the cone is forced into the ground, it is hoped to obtain better correlations between the point resistance and the properties of the soil. In addition, the cuttings carried to the surface by the circulating fluid may permit an approximate identification of the soils encountered.



A W SKEMPTON GEOTECHNIQUE DEC 1948 P 113

FIG A-5 - VANE TEST ARRANGEMENT BY SKEMPTON

Rotary vane tests.- Recent papers by Evans and Sherrat (A-12) and by Skempton (A-33) indicate that the method of determining the shearing resistance of soil in situ by means of a rotating wing auger or vane, see Fig. 17B, was conceived more or less concurrently in Sweden and England. Skempton describes tests with a vane, Fig. A-5,

which is similar to the one developed by **Carlson** (631), but it is used within a cased bore hole and the rotation is continued until the strength of the soil in both its undisturbed and remolded states is determined. The results obtained by Skempton corroborate those described by Carlson, that is, the strength of the soil in situ as determined by vane tests is often greater than that obtained by unconfined compression and other laboratory tests and agrees better with the computed average shearing strength along the surface of sliding of several actual slope and embankment failures. In addition, Skempton found that the strength of remolded clay, as determined by vane tests, was in close agreement with the strength obtained by unconfined compression tests on remolded test specimens.

W H McCART
ST LOUIS DISTRICT CORPS OF ENGINEERS

FIG A-6 - ST LOUIS SPLIT AUGER

A-4 Boring and drive sampling

Miscellaneous equipment.- A split or "removable jaw" auger of the Iwan type, designed by **W. H. McCart** of the St. Louis District, Corps of Engineers, is shown in Fig A-6. One side or half of the auger is connected to the head by a step joint and a single bolt, which easily can be removed when the auger is to be emptied after withdrawal from the bore hole. It is reported that substantial savings in boring costs have been obtained by use of this auger, which is similar to the hinged auger, Fig. 51, developed by the Waterways Experiment Station.

A very simple clean-out jet auger with calyx, designed by **J. D. Parsons** of the firm **Moran-Proctor-Freeman & Mueser** (559 and A-13), is shown in Fig. A-7. This auger has been used with excellent results both by the above mentioned firm and by several drilling contractors. It is manufactured in various sizes by **Sprague & Henwood Inc.** (A-34).

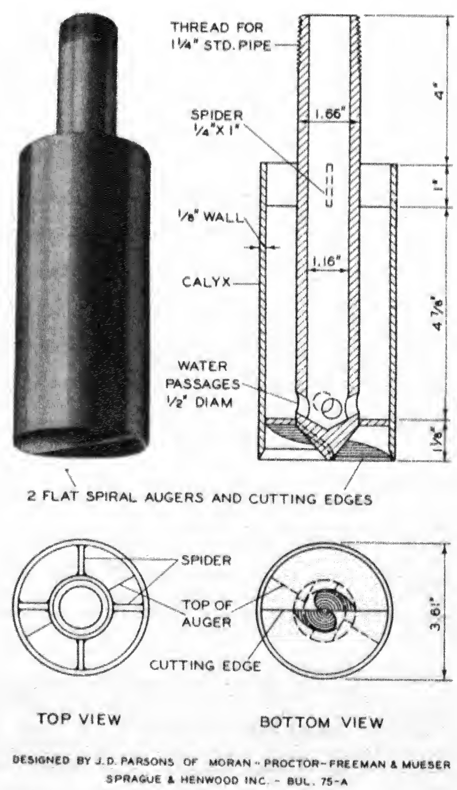


FIG A-7 - M P F M CLEAN-OUT JET AUGER

At request of the **Raymond Concrete Pile Company**, a very simple and

inexpensive spring or finger type core catcher has been developed by the **Barnes-Gibson-Raymond Division** of the **Associated Spring Corporation,** Detroit, and is shown in Fig. A-8. The core catcher is stamped out of a thin sheet of metal and then rolled

STAMPED SHEET METAL
CORE CATCHER
FIG. A-8

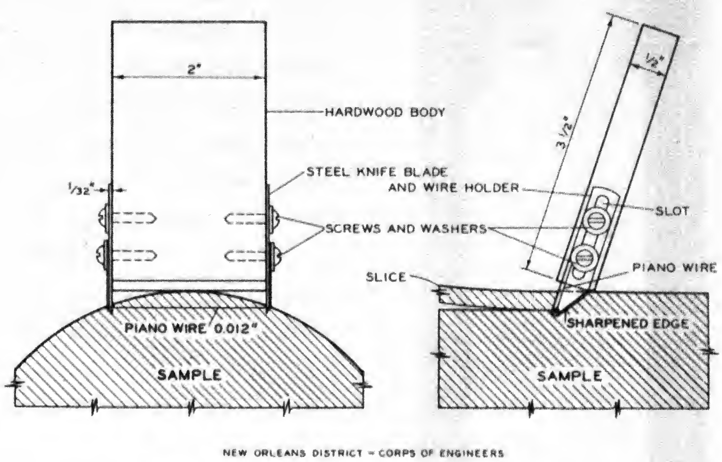


FIG. A-9 - WIRE SAW FOR SURFACE SLICING

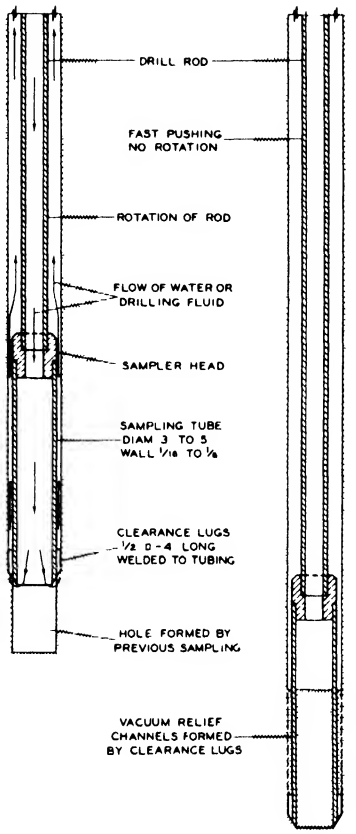
and crimped into shape. The two ends of the crimped base are not welded together, and the consequent spring action allows a small amount of adjustment and assures a smooth fit in the sampler.

A thin longitudinal slice is often cut from the surface of soil samples in order to facilitate preliminary determination of the soil profile and selection of sections to be subjected to laboratory tests. Surface slicing may be performed by means of guides or a miter box similar to those described in Section 16.10, but the use of such auxiliary equipment may be eliminated and the slicing done very rapidly by means of a small wire saw with side cutters and depth guide, Fig. A-9, developed by the New **Orleans District,** Corps of Engineers.

Rotary drilling and drive sampling.- Two methods which combine the principles of rotary drilling and more or less continuous drive sampling have been developed, and it is reported that substantial savings in cost of boring and sampling operations have been obtained when soil conditions permit the use of these methods.

One of these methods, originated by the **Clemard Drilling Co.** of Baton Rouge, is shown diagrammatically in Fig. A-10. The bore hole is uncased but stabilized by means of drilling fluid. The sampler is a thin-wall open drive sampler with a large interior vent and with two small lugs welded to the outside of the barrel near the cutting edge. Preparatory to sampling, the sampler is rotated and drilling fluid is pumped through the drill rod and sampler, whereby the bore hole is reamed to full size and cleaned. Circulation of the fluid is then stopped and the sampler forced into

the soil by the hydraulic feed mechanism of the drilling rig. The two small vertical

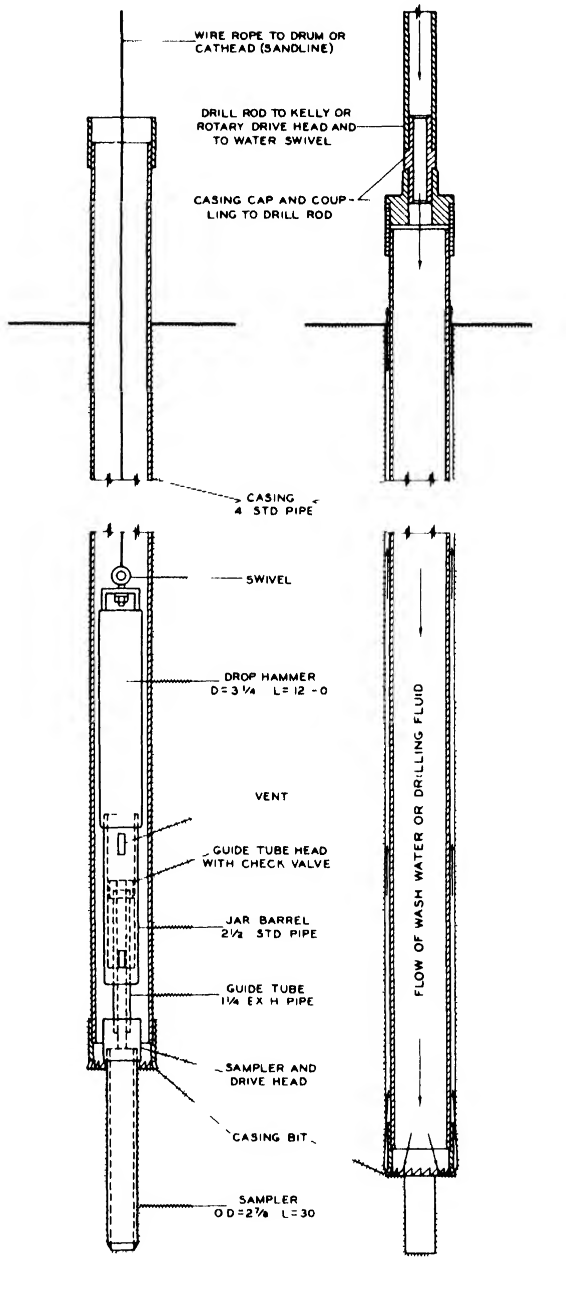


DRILLING SAMPLING

DRIVE SAMPLING AND
ROTARY DRILLING WITH SAMPLER
FIG A-10

channels in the soil, formed by the exterior lugs, serve to break any vacuum which may be formed below the sampler when it again is rotated and withdrawn. After withdrawal of the sampler, the sample is pushed out of the barrel and encased in paraffin.

The other method, developed by the New Orleans District, Corps of Engineers, is shown in Fig. A-11 and is primarily used for reconnaissance exploration of soft or loose deposits. A drive sampler with a guide rod, jar barrel,

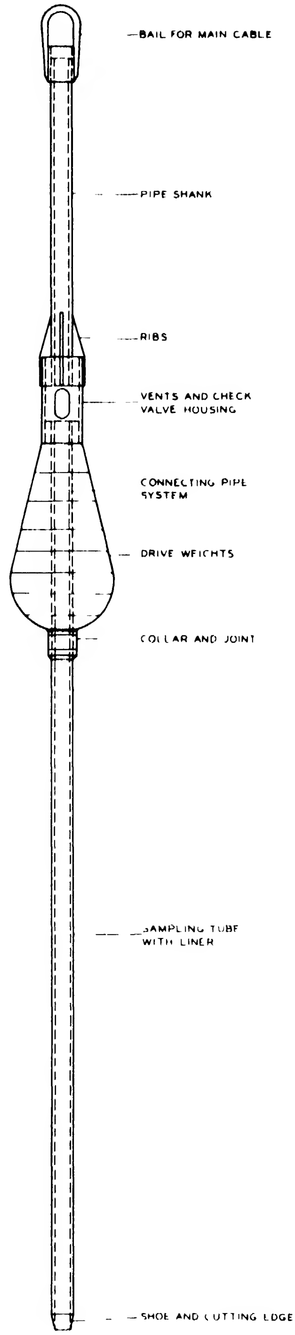


SAMPLING DRILLING

NEW ORLEANS DISTRICT CORPS OF ENGINEERS

DRIVE SAMPLING AND ROTARY DRILLING WITH CASING
FIG A-11

anda slender drop hammer is lowered into the cased bore hole on a cable or the sand line of a rotary drilling rig and is driven into the soil by raising and dropping the hammer. After withdrawal of the sampler, the top of the casing is connected to the kelly or drive rod of the drilling rig and is advanced by rotary drilling, with the casing serving as drill rod and the dentated casing shoe as the drilling bit. The wash water flows down through the interior and up along the outside of the casing and often causes a permanent clearance to be formed between the casing and the soil, in which case it is necessary to use a casing clamp during additions of new sections to or withdrawal of the casing. The samples are removed from the sampler in the field, and after inspection and preliminary classification, representative sections of the samples are selected and preserved for eventual laboratory tests. During driving of the sampler, water in the jar barrel must be forced out through the upper or lower vents. The consequent decrease of the energy delivered to the sampler is avoided in a recent modification, where the jar barrel is eliminated and the guide rod is extended up through a drop hammer consisting of very thick-walled pipe.



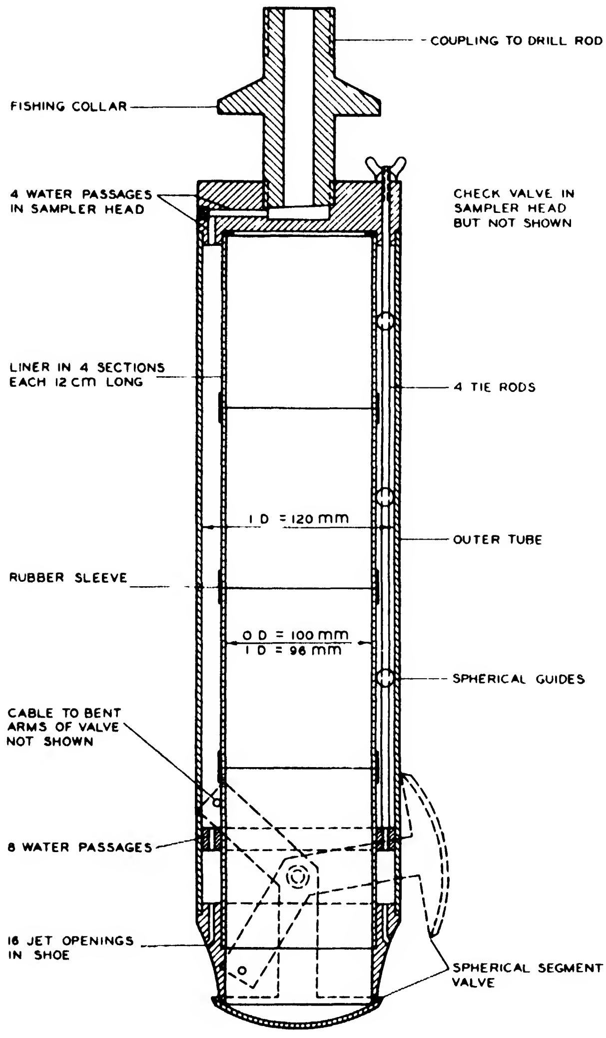
DROP SAMPLER WITH PIPE SHANK

FIG. A 12

Use of free-fall gravity sampler.- The free-fall gravity sampler shown in Fig. 257 has recently been used by the Corps of Engineers for exploration of the bottom deposits of the Mississippi River, in some instances through 200 ft of fast flowing water. It was found that exploration of the upper 10 ft of such deposits could be performed rapidly and economically by means of this sampler, provided the deposits are not too hard and stony and the velocity of the current is small. An improved core retainer is needed to retain samples of extremely soft and loose materials, and difficulties were encountered in sampling through fast flowing water where it appears that the sampler tips over shortly after the start of the penetration. Somewhat better results in sampling through strong currents were obtained by replacing the guide vane section with a 5-ft-long pipe shank, Fig. A-12, and operating the sampler as a regular gravity sampler with the winch running free on the brake during the last part of the drop. Even then it is possible that the sampler tipped over after a short penetration. Successful adaptation of this type of sampler for use in fast flowing water will probably require small-scale model tests in a flume with

transparent sides, so that the action of the sampler can be observed.

Recent German soil samplers.- A sampler developed by **Körste** and described by **Muhs (A-25)** has a special check valve which during withdrawal of the sampler is pressed against its seat with considerable force in order to assure a tight closure. The valve is operated by a rod to a compression spring in the drill rod, and the latter is connected to the sampler by a sliding joint. The valve opens when pressure is applied to the drill rod and the sampler is pushed into the soil, and it closes when a pull is exerted during withdrawal of the sampler.



P SIEDEK ABHANDLUNGEN UBER BODENMECHANIK UND GRUNDBAU 1939 1946 P 67

SAND SAMPLER WITH JETTING AND EXTERNAL VALVE

FIG A-13

A sampler with a jetting arrangement and an external spherical segment valve, Fig. A-13, is described by Siedek (A-32) and is intended for obtaining undisturbed samples of saturated sand. Water is pumped through the drill rod, between the liner and outer tube, and out through the jet openings in the shoe. Circulation is started shortly before the sampler is seated on the bottom of the bore hole. Because of the jetting action, only a slight pressure on the drill rod, and often the weight of the rod alone, is sufficient to force the sampler into the soil. After the desired depth of penetration is reached, a pull is exerted on the drill rod and the valve is closed by means of a wire rope and a sling attached to the two bent arms of the valve. Since the valve is spherical in shape with its center on the axis of the bearings for the actuating arms, its closure will cause very little displacement of soil. To facilitate removal of the sample, the liner is divided into short sections which are held together by rubber sleeves and kept in alignment by spherical guides on the tie rods between the liner and the outer tube.

Sampling of sand by the compressed air method.- Based on a suggestion by **Milton Vargas**, a tentative method for sampling of saturated sand by capping the casing

and replacing the water therein by compressed air is described in Section 11.10. A similar use of compressed air for sampling of saturated sand was conceived concurrently by Glossop (A-16), and at his suggestion the method was investigated experimentally by Bishop (A-4), who simplified it by providing the sampling assembly with an auxiliary barrel or bell for the compressed air instead of capping and unwatering the entire casing.

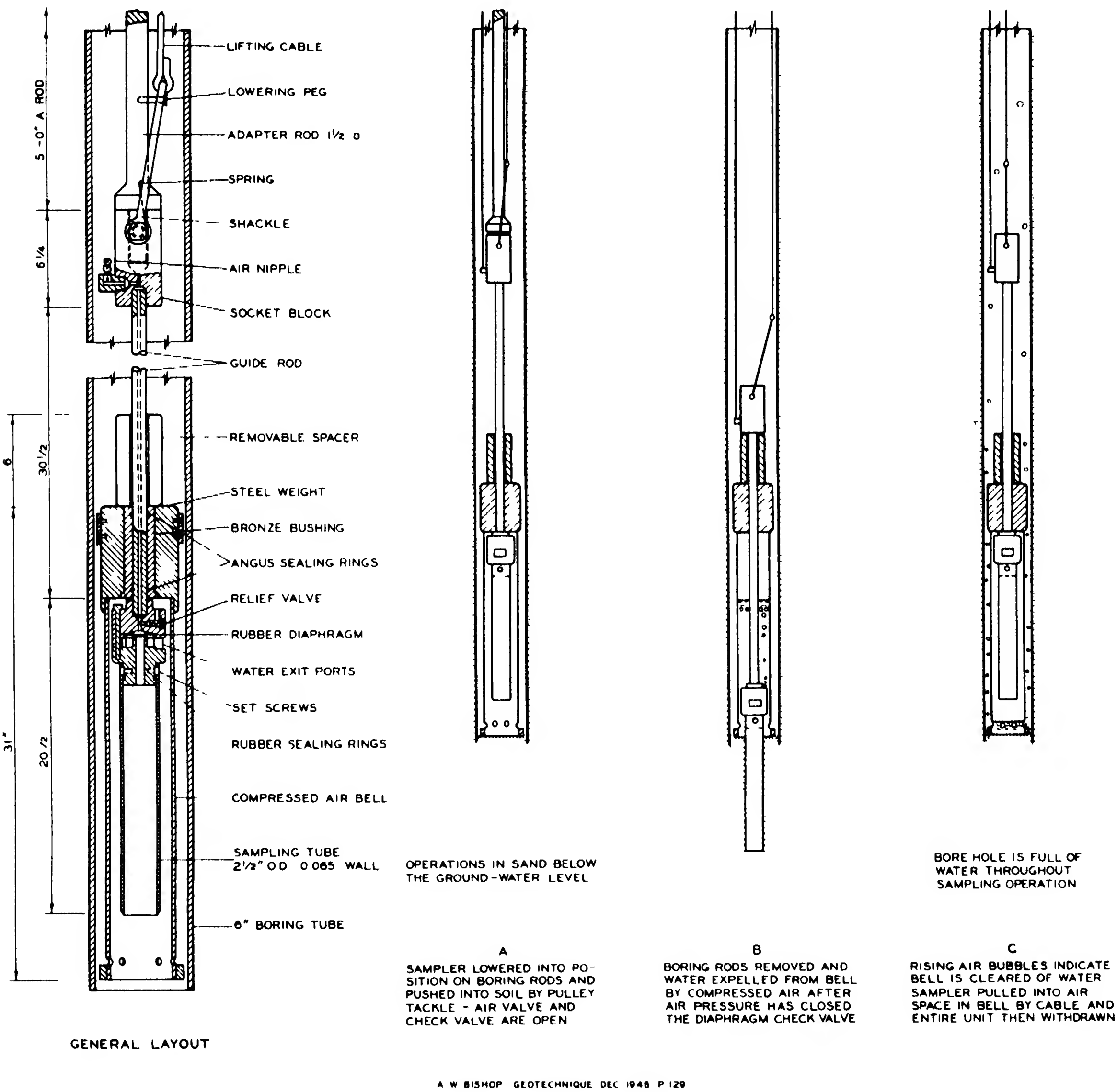


FIG A-14 - SAND SAMPLER WITH AUXILIARY BELL FOR COMPRESSED AIR

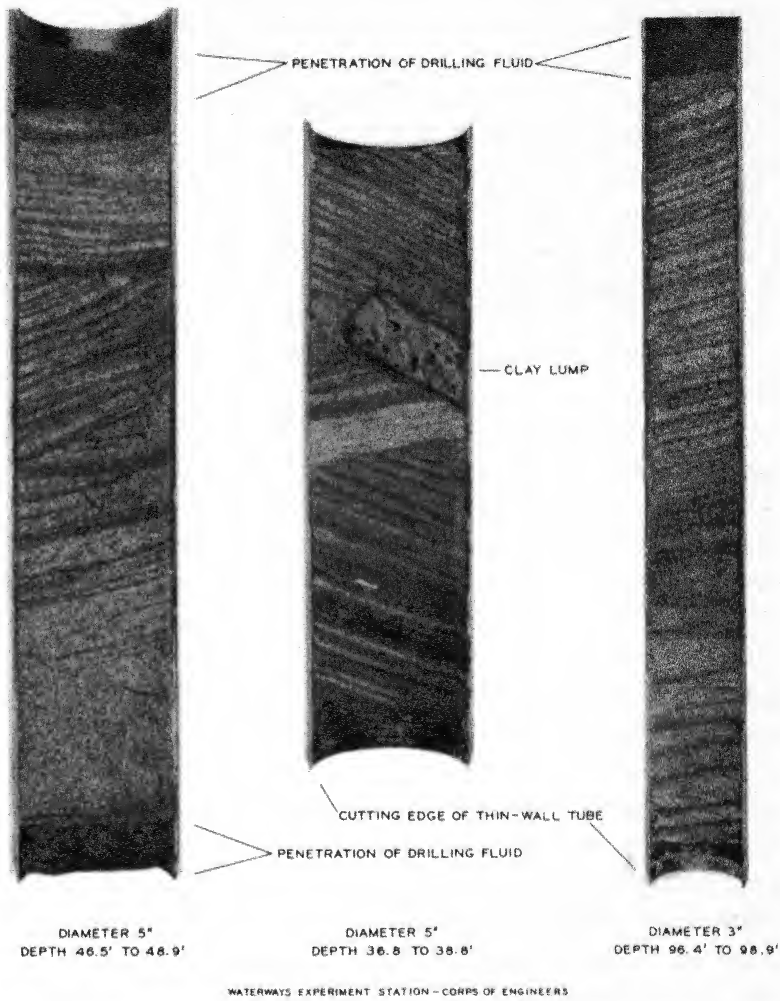
The sampling assembly developed by Bishop is shown in Fig. A-14. The sampler proper is a 2-1/2-in., thin-wall open drive sampler with a novel diaphragm check valve and three large outside vents. The sampler is attached to a hollow guide

rod with a nipple for an air hose, a shackle and cable, and a sliding joint for the drill rod. The compressed air bell is attached to a heavy weight or head which can slide on the above mentioned guide rod. The sampling operation consists of the following steps: (1) The assembly is lowered into the cleaned bore hole, and the sampler is pushed into the soil by means of the drill rod and a block and tackle arrangement, with the spacer block above the bell limiting the length of the stroke. (2) The drill rod is withdrawn, and compressed air is forced into the bell by means of a hand pump. The air passes into the bell through a relief valve which maintains 20 lb per sq in. excess pressure in the sampler head and thereby assures tight closure of the diaphragm check valve. (3) After the water in the bell is expelled, as indicated by rising air bubbles, the sampler is drawn into the bell and the entire assembly rapidly raised to the surface by means of the cable. (4) The spacer block above the bell is removed so that the sampler head can be pushed out of the bell and the sampling tube can be disconnected. Before removal of the tube a filter plug is placed in its lower end, and the suction created by the check valve is then released. Samples of fine-, medium-, and coarse-grained sands below the ground-water level have been obtained without difficulty.

Retention of sand samples by means of drilling fluid.- A very simple and inexpensive method for obtaining undisturbed samples of saturated sand has been developed during recent extensive field investigations by the **Waterways Experiment Station** (A-43), and a detailed report on this method will be published in the near future. It was found that samples of saturated sand could be retained in both 3-in. and 5-in. thin-wall piston samplers, similar to the type shown in Fig. 207A, provided the bore hole is filled with viscous drilling fluid. As soon as the sampler is raised above ground surface, the lower end of the tube is closed with a tight-fitting porous plug. During preliminary operations with a 3-in. piston sampler in a cased bore hole filled with water, only one sample was recovered out of 13 attempts. During the subsequent sampling operations in uncased bore holes filled with drilling fluid, not a single sample was lost in 198 attempts with 3-in. piston samplers and 12 attempts with a 5-in. piston sampler. The samplers were pushed into the soil by means of the hydraulic feed cylinders of a rotary drilling rig, Fig. 37, the depth of penetration was 30 in. and the average length of the samples recovered 27.5 in. All the samples were taken below the ground-water level at depths ranging from 40 ft to 130 ft below ground surface. The composition of the deposits explored ranged from silt and fine sand to coarse sand, and the density from 85 to 110 lb per cu ft dry unit weight.

The density and void ratio variations through most of the samples were determined in the field by the method described in Section 16.9. Other samples were sealed in the tubes and shipped to the main laboratory, where the tubing was cut lengthwise and the samples sliced and photographed. Examples of such photographs are shown in Fig. A-15, and it will be seen that the drilling fluid has penetrated a short distance into the top and bottom sections of the samples. In some cases the

drilling fluid was colored with gentian violet in order to facilitate determination of the limits of the contaminated sections of the samples. The penetration of the fluid into the bottom of the samples was generally less than 1 in. or the distance from the cutting edge required for the sealing plug. Clay lumps similar to the one shown in the center of Fig. A-15 are occasionally found in the upper part of samples when the lower part of the sample previously taken was lost and the bore hole not properly cleaned, Fig. 105A. However, in this case the sand above and below the clay lump appears to be undisturbed, and there were no clay strata immediately above the sample, therefore, it is possible that the clay lump was deposited by the river or rolled onto the sand deposit after a bank failure.



SAND SAMPLES OBTAINED BY PISTON SAMPLERS AND DRILLING FLUID

FIG. A-15

The successful retention of sand samples by means of drilling fluid is probably due to the slight penetration of viscous fluid into the top and bottom sections of the sample and the consequent creation of a more or less impervious seal and a slight cohesion sufficient to sustain arch action in the sand. The friction between a sand sample and the sampler is usually sufficient to retain the sample, and a loss of the sample is generally caused by progressive internal failure of the soil. That the failure takes place gradually is demonstrated by the fact that very little soil is lost from the bottom of the sample while it is pulled out of the soil at the bottom of the bore hole and before the drilling fluid comes into contact with the bottom of the sample. Reduction of pressure in the upper part of the sample and the greater unit weight and pressure of the drilling fluid, compared with water,

may contribute to retention of the sample, but the viscosity and gel strength are probably of greater importance, except when great unit weight is required to prevent caving of the bore hole. The unit weight of the fluid used varied from 64 to 75 lb per cu ft, but the minimum requirements in regard to both unit weight and viscosity have not yet been established definitely since they vary with the soil and ground-water conditions.

The method described requires no other sampling equipment than that used in normal operations. Thin-wall samplers with stationary piston were used, but it is possible that an open sampler with a reliable check valve, Fig. 183, also can be employed successfully. However, the use of a piston sampler has definite advantages, especially when the bore hole is uncased, see Sections 4.12 and 4.13. The method does require a properly proportioned drilling fluid, but this will also in most cases eliminate the need of casing, and the operations referred to were performed faster and at less cost than similar sampling operations in soft clay with the bore hole cased and filled with water.

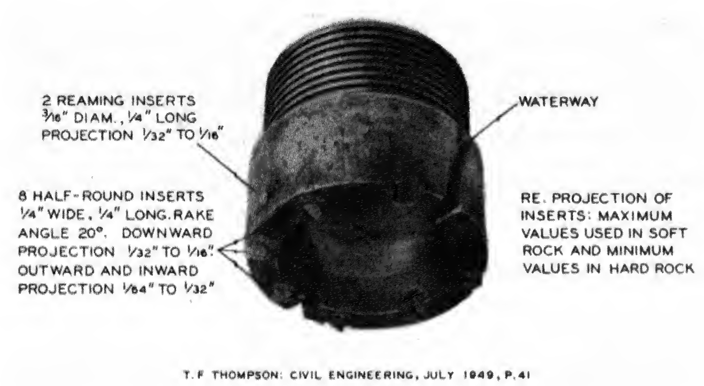
Volume changes of sand during sampling.- One of the principal objects of securing undisturbed samples of sand is to determine the actual and relative densities of the material in situ, and a change in density during sampling, amounting to only a few percent, may cause the samples to be considered unsuitable for the above mentioned purpose. In laboratory experiments with the sampler shown in Fig. A-14 and a prepared bed of uniform sand with an average porosity of 41.5 percent, Bishop (A-4) found that the samples obtained had a porosity of 40.5 percent. This corresponds to an increase of about 1.6 lb per cu ft in dry unit weight of the soil, and it agrees very well with the results of similar experiments by the Waterways Experiment Station, during which a 3-in. thin-wall piston sampler was pushed into a prepared bed of uniform, medium loose sand.

Experiments to determine volume changes of sand during sampling were performed by the **Waterways Experiment Station** in 1947 and 1949, and a preliminary report on the results (A-44) is in preparation. For these experiments sand beds of uniform density were prepared in a shallow, cased hole with a diameter of 3 ft. The relative density of the sand for different series of experiments was varied from very loose to very dense, and the surface of the sand bed was occasionally loaded with lead bars in order to obtain stress conditions corresponding to various depths below ground surface. The sampling was performed with 3-in. and 5-in. thin-wall piston samplers, having special clamping and recording arrangements so that the specific recovery ratio curves and any changes in length or void ratio of the sample after driving could be determined. It was found that the change in density of the sand during sampling primarily depends on the relative density of the deposit and that it may vary from an increase of about 2 lb per cu ft dry density for very loose sand to a decrease of about 1.5 lb per cu ft for very dense sand. However, the change in density also depends to some extent on the degree of saturation, the confining stresses or depth of the bore hole, the diameter and area ratio of the sampling tube, the inside

and outside clearances provided by the shoe and cutting edge, the depth of penetration or length of sample, and on the method used to force the sampling tube into the material.

A-5 Core boring

Tungsten carbide inserts.- An example of a core bit with tungsten carbide inserts is shown in Fig. A-16. This bit was developed by the Geology Section and the Core Drill Unit of The Panama Canal and is described by Thompson (A-36). The inserts are hand-set in commercially available blank bits of low carbon steel. Since 1940 this type of bit has been used in over 95 percent of the core drilling operations in the Panama Canal Zone, and it has been found to be efficient and economical in use except in the hardest locally encountered rocks, such as dense basalts, andesites, and rhyolites. The depths drilled with a single bit varied from 10 ft in hard rock to 700 ft in soft rock, and the average was slightly less than 100 ft.



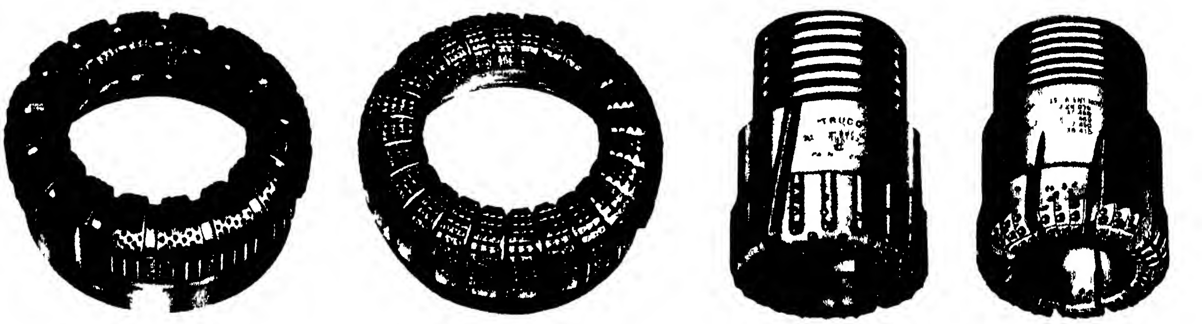
"NX" CORE BIT WITH TUNGSTEN CARBIDE INSERTS
FIG A-16

Diamonds.- As indicated on page 338, the two main classes of industrial diamonds are carbons and bortz, and the latter are currently used in the great majority of diamond core bits. In a more detailed classification, the industrial diamonds are generally designated by the country of origin, and those from the Belgian Congo are often considered as a special group and called congos. The quality and cost of the diamonds vary greatly and should correspond to the character of the rock in which the core bits are to be used. In a memorandum of June 1949 to the Chief of Engineers, U. S. Army, the Diamond Core Bit Committee of the **Industrial Diamond Association** made tentative recommendations for classifications and uses of industrial diamonds in core bits, and these recommendations may be summarized as follows:

Diamonds Description	Diamonds Origin	Types of Rock in which Core Bits Are to Be Used
Round	West Africa	Hard to very hard. Sound or cherty
Semi-round	West Africa	Fractured, igneous or metamorphic
Cast	West Africa	Medium hard rocks. Sound sandstone
Round	Congo	Clay shales. Fractured sandstone
Semi-round	Congo	Sound chalk and indurated clays

The size of the stones should be varied in accordance with the size of the bit, the character of the rock, and the type of diamonds used. The sizes suggested for West African diamonds vary from 6 to 40 stones per carat and for congos from 3 to 12 stones per carat. The smallest stones are used in hard rock and small bits and the largest in soft rock and large bits. The total weight of diamonds in standard bits is about 8 carats of West African diamonds or 10 to 15 carats of congos per square inch of the projected flat surface of the crown of the blank bit. The larger unit weight of congos applies to EX bits and the smaller to bits larger than the NX size. A matrix of standard hardness is recommended for use in all soft rocks and also in sound and uniform hard rocks, whereas a hard matrix is preferable in cherty formations and in fractured hard rock.

Diamond core bits.- Recent developments of large diamond core bits for use under adverse conditions in oil well drilling may possibly benefit the design of the smaller core bits used in explorations for mining and civil engineering purposes. Examples of recent diamond core bits of regular sizes and patterned after the larger bits are shown in Fig. A-17B.



STANDARD — "W" TYPE — STANDARD — 'W' TYPE

A - LARGE OIL FIELD CORE BITS - SIZES 4¼" TO 8¾" — B - REGULAR CORE BITS SIZES "E" TO "N"

WHEEL TRUEING TOOL CO DETROIT

FIG A-17 - RECENT DIAMOND CORE BITS

Difficulties encountered in the design and use of diamond core bits for oil well drilling arise not only from the size of the bits but also from control of the feed pressure at great depths, relatively slow speeds of rotation of the rotary table of the drilling rigs, erosion of the matrix by the viscous and grit laden drilling fluid at high rates of circulation, and mudding-up or "burning" of the bit at too low rates of circulation. Many of these difficulties have apparently been overcome during the last few years, especially by development of special matrices and bit settings which provide better circulation and facilitate cooling of the bit and rapid removal of the cuttings. A variety of matrices and bit settings have been developed for use in various types of rock, ranging from very soft rock to fractured and cherty materials. Examples of such bits, manufactured by the **Wheel Trueing Tool Company (A-46)**, are shown in Fig. A-17A. In comparison with bladed and roller core bits, Fig. 282,

diamond bits provide cores of greater diameter and length, a smoother surface and less breaking of the core, larger recovery ratios, and increased rates of progress in drilling. Cores of sound rock up to 50 and even 90 ft in length are regularly being obtained, and in some cases it has been more economical to use diamond core bits instead of straight drilling with standard non-coring rock bits, Fig. 44, in which case continuous cores are obtained without extra cost.

Core barrels.- Based on experiments by **F. Pickard** and S. A. **Tyler** (A-39), a diamond core barrel which is intermediate between the double tube swivel and the bottom discharge types, Fig. 280 and 281, has recently been developed by **Sprague & Henwood Inc.** (A-34) and is shown in Fig. A-18. This core barrel and its longer bit with box type instead of the usual pin type coupling have recently been accepted as standards by the **Diamond Core Drill Manufacturers Association.**

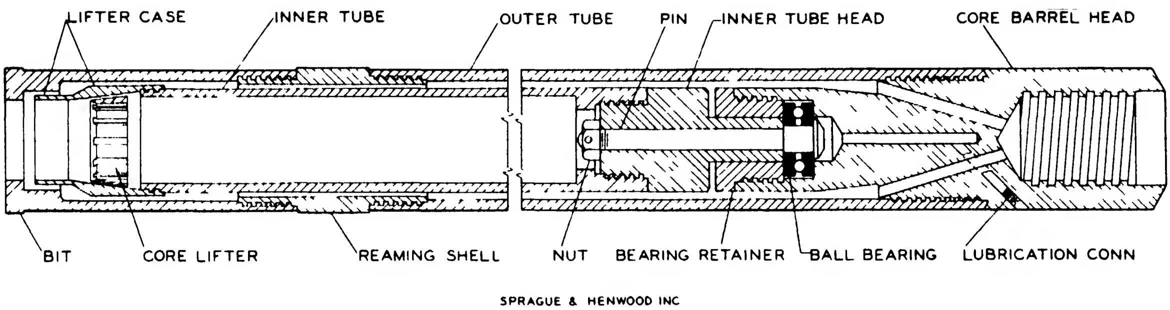
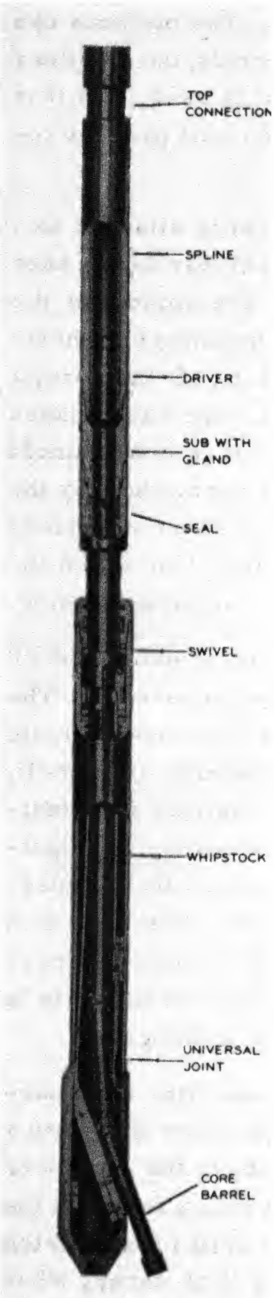


FIG A-18 - S&H SERIES "M" DOUBLE TUBE CORE BARREL

In the ordinary double tube core barrel, Fig. 280, an inside taper in the pin of the bit forms the seat for a fluted, split ring core lifter, and the wash water has to pass between the core lifter and the bit and core. When mineral grains are lodged between the bit and core lifter, the latter will tend to rotate with the former and may cause grinding and breaking of cores of fissured and/or relatively soft rocks with resulting ultimate blocking of the core barrel. The inner tube of the core barrel shown in Fig. A-18 has a tapered extension or shell which forms the seat for the core lifter and extends close to the face of the bit. As a consequence, the tendency of the core lifter to rotate with the bit, the length of core exposed to fast flowing wash water, and the danger of blocking of the core barrel or erosion of the core are greatly reduced. In broken and soft rocks much greater recoveries have been obtained with this core barrel than with the ordinary, double tube, swivel type core barrel.

Reverse circulation coring.- Cores of sound rock, not subject to erosion by the circulating drilling fluid, can be recovered by reverse circulation coring, during which the drilling fluid is pumped down through the annular space between the drill pipe and the walls of the hole and returns to the surface through the drill pipe. The method requires internal flush drill pipe and core barrels, and generally also special core bits, and that the casing be extended to sound rock or to the formation being

cored. Sections of the core broken off by direct action of the bit or by means of core lifters, which are activated when the bit is lifted off the bottom before adding a new section of drill pipe, are moved up through the drill pipe by pressure of the circulating fluid. Formerly the core sections passed out through a special swivel and into a basket, but in current operations they are generally gathered temporarily in a core retriever below the kelly. This core retriever is a long section of pipe with an internal diameter slightly larger than that of the drill pipe and with core catchers at its lower end. The retriever is emptied of accumulated core sections whenever the coring operations are interrupted to add new sections of drill pipe.



ROTARY TYPE
SIDE WALL SAMPLER
FIG. A-19

Earlier attempts to use reverse circulation coring were only partially successful since small irregular sections of the core often became wedged in and blocked the drill pipe, and removal of the obstruction required temporary reversal of the flow or withdrawal of the pipe. With the advent of efficient diamond coring bits, which produce a smooth cylindrical core and do not break it into irregular sections, the method has been used with considerable success. The recoveries are often close to 100 percent when the rock is sound, and in one instance 399 ft of continuous core of hard sandstone was obtained in four days without withdrawing the bit from the bore hole, **Adamson (A-1).**

Rotary type side wall sampler.- The side wall samplers described in Section 14.6 are all drive samplers and may cause crushing or cracking of the samples when used in dense or brittle materials. A rotary type side wall sampler, which is operated as a wire-line core barrel, has been developed by the **A-1 Bit & Tool Co.**, see (A-47), and is shown in Fig. A-19. A whipstock unit with a swivel joint is attached to the drill pipe and lowered to the desired depth, where preliminary circulation of drilling fluid is established to remove shavings and other obstructions from the face of the whipstock and mudcake from the walls of the hole. The rotary side wall sampler, which is connected to the latch and spearhead section by a universal joint, is then pumped or dropped through the drill pipe. The small core barrel is deflected by the whipstock and drills into the wall of the hole when the drill pipe is rotated. The inside diameter of the small core barrel is 1-1/4 in., and its inclination during coring is 20°. Completion of the coring is indicated by a rise in pump pressure, and the core barrel assembly is then withdrawn by means of a wire line and overshot as an ordinary wire-line core barrel.

Orientation of core barrels.- Difficulties in direct orientation of cores by orienting the core barrel are discussed briefly in Section 14.9. Some of these difficulties are eliminated by methods recently developed by the **Eastman Oil Well Survey Company** (A-47) and described in detail by **K. Carlsten**(A-19). The methods can be used with both conventional core barrels and wire-line core barrels, but in either case a double tube barrel with a floating or swivel type inner tube is used, and it is assumed that a stiff spring type core catcher in the inner tube shoe will prevent rotation of this tube during the actual coring.

When the bore hole is vertical, or nearly so, the core barrel is attached to a non-magnetic drill collar, and the inner tube has a small point or scriber in the shoe which scratches a vertical line on the core as it enters the tube. The spindle of the inner tube is extended to the top of the core barrel head and is surmounted by a horizontal pin in alignment with the scriber in the shoe. Before breaking off the core, a special single shot direction indicator is lowered through the drill pipe and engages the pin on the spindle of the inner tube. A lug in the indicator unit is in alignment with the pin and the scriber and is photographed with the compass card, whereby the direction of the scriber is determined. Determination of the dip and strike of various strata is facilitated by placing the core sections in a special "reader" in which the position of the scriber, indicator disk, and inclination of the hole can be duplicated.

A simplified method is used in bore holes with an inclination in excess of 2° and when the drift and direction of the hole are known or determined separately. The scriber in the shoe of the inner tube is eliminated, and the expensive non-magnetic drill collar is replaced with a special substitute or coupling containing two small, diametrically opposed magnets. Before breaking off the core, a modified drift indicator is lowered through the drill pipe and seated in the special coupling. The indicator disk can rotate and contains a small magnet which will be aligned with the magnets in the coupling. The record on the photograph of the indicator disk will then show both the drift of the hole and the azimuth angle between a line through the magnets and the low side of the hole. After withdrawal, the line through the magnets is projected optically to the bottom of the core barrel and is marked on the core.

A combination of the two methods is used for orienting a wire-line core barrel in inclined holes. The wire-line core barrel has a swivel type inner tube with a scriber in its shoe, and the tube is connected to a drift indicator above the core barrel head in such a manner that the scriber always is in alignment with a mark on the indicator disk. Before lowering the entire assembly through the drill pipe, a watch in the drift indicator is set for the time required to drill about 2 ft of core. When this time has expired, the operations are stopped until the indicator record is made, whereupon the assembly is withdrawn. The indicator record then shows the azimuth angle between the scriber and the low side of the hole.

A-6 Bore hole or well logging methods

General methods.- The field methods used to determine soil and rock profiles

TABLE A-1 - METHODS OF BORE HOLE OR WELL LOGGING

METHOD	OPERATION	APPLICATIONS AND LIMITATIONS
DRILLERS LOG	Observation of action of the tools and estimates of rates of progress	The observations and rough examinations of the cuttings form the basis for the drillers estimates of character and boundaries of formations and when to start sampling
SAMPLING OF CUTTINGS	Collection, examination, testing samples of cuttings from drilling fluid, wash water or bailed slurry	Preliminary qualitative identification of strata Samples generally contaminated by foreign materials, fine-grained constituents missing, partial solution of others
REPRESENTATIVE SAMPLING	Securing, examination, and testing representative disturbed or undisturbed soil samples or rock cores	Required for positive identification of materials and correlation of results obtained by other methods Limitations expensive, possible contamination or disturbance of samples, incomplete unless sampling continuous recovery 100 percent, and all material tested
DRIVING OR PENETRATION RESISTANCE	Determination of dynamic or static penetration resistance of sampler during drive sampling operations	Advance estimates of strength and relative density of strata Correlations influenced by equipment, methods of operation water levels, depth of bore hole, etc
ROTARY DRILLING RESISTANCE OR DRILLING RATE	Direct observation but preferably continuous recording of rate of progress or time required per foot advance of drilling or coring bit	Detailed indication of relative hardness and lithologic changes, character of lost core sections, correct position of recovered sections, efficiency of procedures and equipment, data produced as work progresses
DIAMETER OR CALIPER LOGGING	Measurement of variations in bore hole diameter with depth and time by three- and four-armed calipers Mechanical or electrical recording	Estimates of volume of bore hole and cement for packing behind casing Detection of eroded or squeezed sections before setting casing and whipstocks taking side wall samples Indicates cavities, changes in strata
TEMPERATURE LOGGING	Direct measurement or electrical recording of temperature changes, with depth and time, in drilling fluid after its circulation ceases	Lithologic changes, entrance of water or gas into well, cement level behind casing are indicated by differences in final temperature gradients and especially by anomalies in gradients during establishment of equilibrium
SPONTANEOUS POTENTIAL OR S P LOGGING	Measurement of variations in potential of drilling fluid, caused by electrochemical and electrokinetic action of the fluids in the boring and in the pores of soil and rock	Spontaneous potential and resistivity logs are complementary and generally obtained or used concurrently for determination of stratigraphic profiles, locating casing couplings and cement packing, relative data on porosity or volume and nature of pore fluids, some quantitative results by correlation with tests on undisturbed cores Conditioning of drilling fluid may be required Neither method is applicable within casing and only resistivity measurements with scratcher type electrodes possible in dry holes and in non-conductive oil-base drilling fluid
RESISTIVITY LOGGING	Measurement of apparent resistivity or impedance of the strata with current and potential electrodes various arrangements and spacings	
INDUCTION LOGGING	Measurement of apparent conductivity of strata with A C field, created by oscillator and transmitter coil and acting on a receiver coil	Principles and results similar to those of resistivity logging, but induction method can be used in dry holes and with oil-base drilling fluid Better indication of thin strata, simpler interpretation of results claimed
NATURAL RADIOACTIVITY	Measurement of intensity of gamma rays emitted by formations Use of Geiger counter, ionization chamber	The two methods are complementary Intensity of primary gamma rays indicates character of solids and that of the secondary gamma rays amount of hydrogen in pore fluids Special porosity tests and location of cement packing with carnotite tracer admixture in drilling fluid Can be used in cased and open borings and with contaminated drilling fluid Flexibility, simple operation and interpretation of results claimed
ARTIFICIAL RADIOACTIVITY	Measurement of intensity of secondary gamma rays, created by neutron source below ionization chamber and acting on hydrogen in pore fluids	
DIPMETER SURVEYS	Simultaneous S P or resistivity measurements with three recording electrodes, spaced 120°, and oriented by drift-direction indicator	The relative depths of formation boundaries, as indicated by the three logs, and orientation by drift-direction indicator determines dip and strike of the strata
VISUAL SURVEYS	Use of periscope with light source in dry and shallow holes and deep-well camera in fluid-filled holes	Securing visual evidence of cavities, channels, faults, fractures, seams, dip and strike of strata, the general structure, and the form of pores in pervious formations

and the composition or properties of the various strata during the advance and after completion of a boring are called bore hole or well logging methods. A summary of the principles and applications of these methods is presented in Table A-1, and the first four methods listed are the general or commonly used methods. Limitations of estimates based on the drillers log, examination of cuttings, and determination of the penetration resistance of drive samplers have been discussed in previous sections; and it is emphasized that representative or undisturbed samples are required for positive identification of the materials, determination of certain physical properties, and correlation of results obtained by other methods of subsurface exploration or bore hole logging.

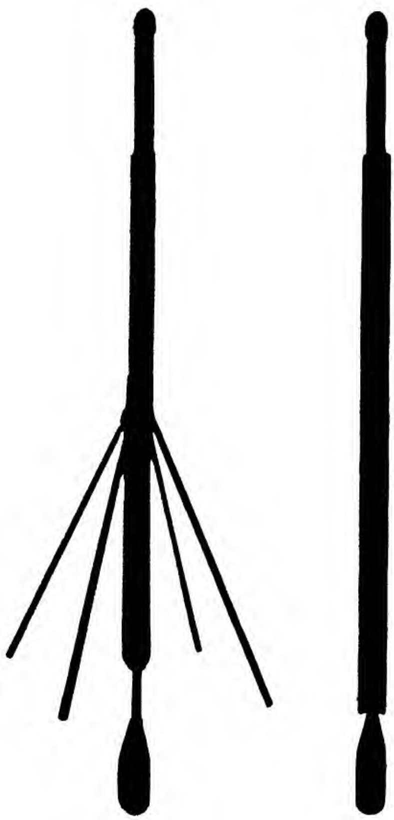
The securing, examination, and testing of representative and especially undisturbed samples are expensive, and although this method of bore hole logging is required to complete the exploration, it is subject to the following deficiencies: (1) Thin but important strata may remain unnoticed when fully continuous samples are not obtained. (2) When the recovery ratio is less than 100 percent, it may be difficult to place recovered sections of a sample or core in their correct stratigraphic position. (3) The samples may be contaminated by entrance of water, drilling fluid or filtrate of the fluid, and the physical properties may be altered during shipment, storage, and handling of the samples. (4) It is seldom that all the material recovered can be tested or subjected to a particular type of test, and estimates of the average properties of a stratum or series of similar strata are generally based on those of relatively few sample sections or test specimens.

Special methods.- A variety of special well logging methods have been developed or greatly improved during recent years and are widely used in drilling for oil. These methods supplement the general methods, and their use not only increases the accuracy or completeness of estimates of subsurface conditions but will generally also decrease the total cost of exploration by facilitating certain phases of the work or by reducing the number of samples required. The summary description of these methods in Table A-1 will only be supplemented by a few additional comments in the following paragraphs, and for more detailed information reference is made to **Heiland (214)**, **Jakosky (221)**, **LeRoy and Crain (A-19)**, and to bulletins by individual firms in the **Composite Catalog (A-47)**. Possible uses of these methods in explorations for civil engineering purposes will be discussed in the closing paragraphs of this section.

Drilling rate logging.- Until a few years ago, determination of the rate of progress during rotary drilling or core boring was confined to direct observations or estimates by the drillers, but apparatus for continuous recording of this rate or the drilling time have been developed and found to be extremely useful. Mechanically operated recorders known under the trade names "Geolograph" and "Log-O-Graf" indicate the time required per foot penetration on a time scale or a depth scale, whereas a third, hydraulically operated type furnishes diagrams from which the rate of penetration in feet per hour can be determined by comparison with standard diagrams; see **G. F. Shepherd and P. B. Nichols (A-19)**, **Warren Automatic Tool Co. (A-47)**.

The drilling rate records are often very detailed and informative in regard to stratigraphy and they have the great advantage that they become available as the drilling progresses and thereby assist the driller in determining when changes in equipment and methods of operation are required, and when even minor changes in subsurface conditions occur and samples should be obtained.

Diameter or caliper logging.- Because of erosion by the drilling fluid, abrasion by whip of the drill pipe, caving, squeezing, and formation of mudcake, the diameter of a bore hole is seldom equal to the nominal bit diameter. Calipers for determination of variations in the bore hole diameter have been developed by **Halliburton Oil Well Cementing Company (A-47)** and have three or four arms which are in contact with the walls of the hole during the logging operation, Fig. A-20. While the caliper is being lowered into the hole, the arms are held in closed position, but they can be released electrically at any desired depth or by seating the caliper at the bottom of the hole. During withdrawal of the instrument, the movements of the arms are recorded either mechanically on a small chart in the body of the caliper, or transmitted electrically to a recorder at the ground surface. The latter or regular type of caliper has a diameter of 3 in., Fig. A-20, and a maximum range of measurement of 32 in. Variations in the hole diameter are indicative of the character of the materials, and caliper logs often supplement logs obtained by other well logging methods. However, the principal use of caliper logging is in preparations for various operations, such as setting and cementing of casing, placing of whipstocks, and side wall sampling.



HALLIBURTON OIL WELL CEMENTING CO

FIG A-20 - BORE HOLE CALIPER

Temperature logging.- Determination of continuous temperature profiles of borings is called temperature logging and has been facilitated by recent improvements in recording bimetallic or electrical resistance thermometers, which respond very quickly to temperature changes. Immediately after stopping circulation of the drilling fluid, the temperature of the fluid near the top of a deep boring will be greater than that of the surrounding soil and rock and vice versa in the lower part of the hole. During the subsequent establishment of temperature equilibrium, the rate of cooling or heating of the fluid at various depths depends on the thermal conductivity of the corresponding strata, and anomalies will be developed in both the intermediate and final temperature gradients. These anomalies are generally most pronounced 24 to 36 hours after cessation of circulation. Temperature logs furnish fairly detailed indications of formation boundaries and especially of the depths of

cement behind casing and at which gas, oil, or water flows into the boring. The setting of cement or an inflow of relatively warm water causes a localized rise in temperature of the drilling fluid, whereas gas expands with consequent cooling upon entering the bore hole.

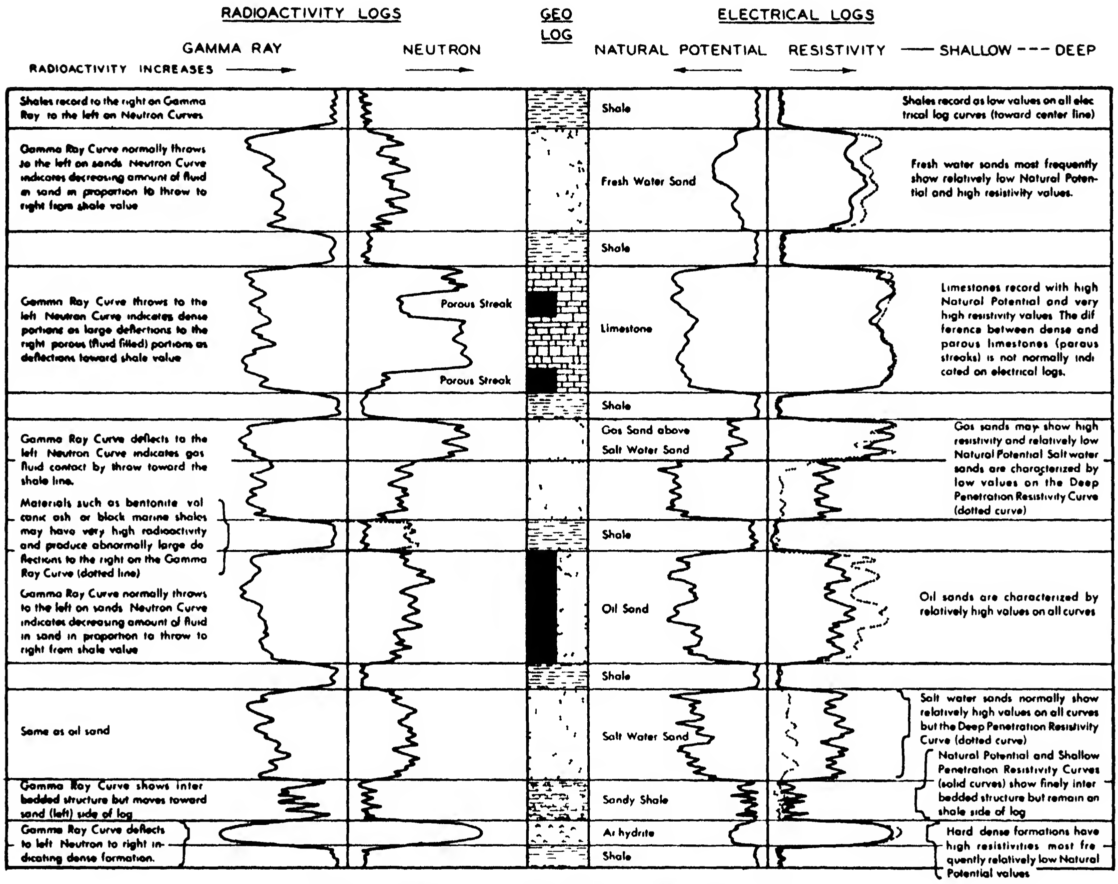
Electrical methods.- The oldest and most commonly used of the special well logging methods consist in measuring variations in the natural or spontaneous potential -- called S.P. -- of the drilling fluid and determining the apparent resistivity of the strata encountered. The natural potential is principally the result of electrochemical action between the fluids in the bore hole and in the pores of the surrounding materials, although the electrokinetic or electrofiltration potential, caused by a flow of fluid through the pores, may be a contributing factor. Resistivity logging is similar in principle to the electrical resistivity methods for subsurface exploration, Section 2.3. Various arrangements and spacings of the electrodes are used for deep or shallow penetration, depending upon whether the principal purpose is to determine details of stratigraphy or actual resistivities. Spontaneous potential and resistivity logging are more or less complementary methods, and with recent equipment both types of logs may be obtained concurrently. The response of these logs to some typical conditions in oil well drilling is presented in a diagram by **Lane-Wells Company (A-47)**, which is reproduced in Fig. A-21.

The natural potential and the actual resistivity of the strata depend on the volume and composition of fluid in the pores, and this dependency is reflected in the logs obtained. However, the measured potentials and resistivities are also influenced by the composition of the drilling fluid and other factors, and it has not been possible to establish definite quantitative relationships between the measured values and the porosity and fluid content of the strata. Nevertheless, approximate quantitative determinations may in some cases be made by means of electrical logs when the results of tests on undisturbed samples from the same boring are available for the purpose of correlation. Neither S.P. nor resistivity logs can be obtained within casing, and only resistivity logging is possible in holes which are dry or filled with non-conductive, oil-base drilling fluid. In the latter case it is necessary to use electrodes with scratchers or springs to maintain contact with the walls of the hole, but the efficiency of this contact may vary when the rock is hard or the diameter of the hole is subject to irregular variations.

The above mentioned difficulties can be eliminated by use of the induction method of resistivity logging, which does not require direct contact between the instruments and the fluid or subsurface materials. In a brief description of the method, it is stated by **H. G. Doll (A-19)** that the flow of current in this case is of the radial type, and that coil systems can be designed to obtain a focusing effect, so that the resistivities or conductivities can be determined with greater accuracy and the results be interpreted easier than those obtained by conductive resistivity logging. Efficient equipment for induction logging was developed only recently, and the method has primarily been used in cases where other electrical methods do not furnish

satisfactory results.

Radioactivity logging.- Measurable radioactivity is found in all kinds of rock, and the relative intensity of the gamma rays emitted can be determined by means of



These generalized curves are presented to illustrate the most typical response of Radioactivity and Electrical Logs to various types of formations These typical curves should not be used as criteria for the analysis of any particular log since in practice a wide range of response may exist

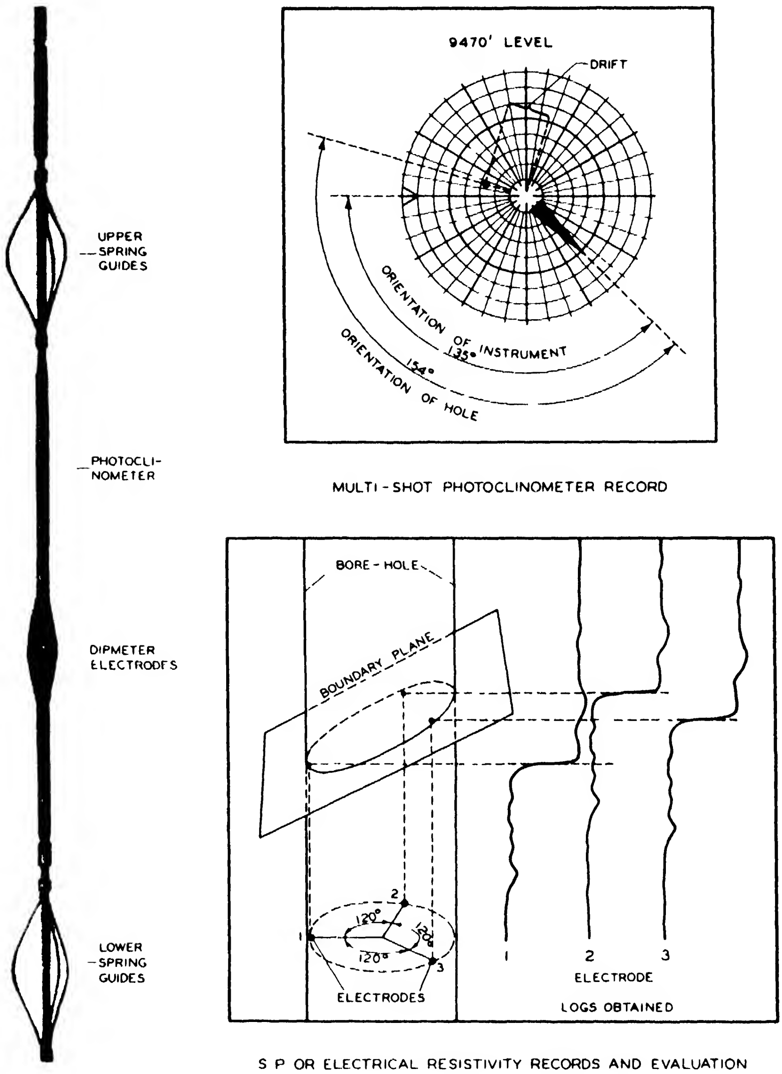
LANE-WELLS COMPANY - COMPOSITE CATALOGUE OF OIL FIELD AND PIPELINE EQUIPMENT - 1948 P 2202

FIG A-21 - TYPICAL RESPONSE OF ELECTRICAL AND RADIOACTIVITY LOGS

an ionization chamber. The log thus obtained furnishes information on the stratigraphic profile as shown in Fig. A-21. The natural gamma ray log is generally supplemented by a log of artificial radioactivity, induced by bombarding the subsurface materials with fast moving neutrons from a strong neutron source below the ionization chamber, which in this case is so designed that it responds only to the artificial and not to the natural gamma rays. When the neutrons encounter hydrogen in the strata or pore fluids, they will be stopped or their speed decreased with a consequent decrease in artificial radioactivity with increasing amounts of hydrogen encountered. In combination with the gamma ray log, the neutron log can be used to estimate the relative porosity and fluid content of the strata. A radioactive tracer, such as carnotite, may be added to the drilling fluid for special tests, and by comparing

gamma ray logs taken before and after addition of the tracer, the penetration of the fluid into the pores and the relative permeability of the strata may be estimated. In a similar manner, the travel of cement behind the casing may be determined by adding carnotite to the cement before injection.

The practical development of radioactivity logging has been accomplished within the last few years, and the method is not yet applied to the same extent as electrical logging. The method can be used under most conditions, in cased and open borings and whether dry or filled with any type of drilling fluid, and the only limitations are that the temperature should not exceed 230° to 250° Fahrenheit, and that surface conditions and probably cosmic rays may interfere with measurements less than 50 ft below ground surface. Simple field operations and easy interpretation of the results obtained are claimed for the method, V. J. Mercier (A-19), **Lane-Wells Company** (A-47).



SCHLUMBERGER WELL SURVEYING CORP COMPOSITE CATALOG OF FIELD AND PIPELINE EQUIPMENT - 1948 - P 3735

FIG A-22 - PRINCIPLES OF ELECTRICAL DIPMETER SURVEYS

Dipmeter surveys.- Determination of the dip and strike of subsurface strata by means of electrical well logging methods is called dipmeter surveying. Depending on the character of the strata and composition of the drilling fluid, either the spontaneous potential or the resistivity method may be used. The method developed by **Schlumberger Well Surveying Corporation** (A-47) employs standard cable and surface recording equipment, but three recording electrodes are attached to a mandril with spring guides and containing a multi-shot dip-direction indicator, Fig. A-22. The

best results are obtained for relatively thin strata with sharp contacts and especially for thin beds of limestone and sandstone in shale. The results obtained by dipmeter surveys have been very valuable in solution of stratigraphical problems in virgin areas and when complex structures are encountered.

Photographic surveys.- A deep-well camera described by O. E. Barstow and C. M. Bryant (A-19) consists of a modified 16-mm movie camera with a wide angle lens, film magazine for 450 exposures, and an electrical release mechanism for single exposures. The camera, facing downward, is placed in a cylindrical, air-filled housing or pressure chamber with an outside diameter of 4-1/2 in. Opposite the lens is a small window to a lower chamber filled with clear water and containing a 45° mirror, electric bulbs, a regulating bellows, and a large window in the side wall. Springs outside the camera housing and opposite the picture window press the latter against the side of the hole to be photographed, thus decreasing the obscuring effect of the drilling fluid. Excellent photographs have been obtained even in relatively turbid fluid, but heavy oil base fluid must be replaced with water or the clearer water base fluids before photographs can be obtained. The camera is usually lowered into the hole on a cable containing the necessary electrical circuits, in which case the picture window tends to face the low side of the hole. When the camera is attached to the drill pipe, the direction of the picture window can be controlled by orienting the drill pipe or by means of a drift-direction indicator. A deep-well camera for 35-mm film and also a deep-well television device are in process of development.

Applications in civil engineering.- Some of the special methods of bore hole logging may possibly be used to advantage in subsurface explorations for civil engineering purposes, in some cases by providing supplementary details or indicating irregularities overlooked in normal operations, and in other cases by facilitating determination or improving estimates of the average physical properties of thick deposits or a series of similar strata.

Apparatus for recording the drilling time or rate would be useful when extensive core boring operations are required. The drilling rate logs would correspond to diagrams obtained by determination of the penetration resistance during sounding tests and drive sampling operations. They would help to locate soft seams and fault zones of which cores are not obtained, and would furnish information on the relative toughness or hardness of the strata encountered.

In the exploratory borings for Norris Dam, a so-called "feeler" with two pronged arms was used to locate soft seams and cavities in the rock, **Lewis (949)**. This instrument may be regarded as a forerunner for the recently improved bore hole calipers, Fig. A-20, but the latter will undoubtedly provide additional details and greater accuracy in determination of variations in the bore hole diameter. Knowledge of the actual hole diameter would be useful in placing sand and gravel filters in wells or vertical drains and in reaming out the lower part of bore holes for certain types of cast-in-place concrete piles. Repeated calipering of a bore hole over a period of time may yield information on the swelling potentialities of certain clays

and shales, slaking of other shales, and internal erosion of sand and silt strata.

Temperature logging may possibly be used to detect cavities, fissured or water bearing strata, and to trace the sources of subterranean flows of water. However, in the interpretation of temperature logs of relatively shallow borings, the influence of seasonal and long term changes in surface temperatures may have to be taken into consideration.

Electrical logging, especially of reconnaissance borings, may help to establish more detailed and reliable soil profiles and would probably indicate stratifications in massive deposits, otherwise judged to be uniform in character. In case of borings in rock, electrical logs would indicate the presence of cavities and fissures, furnish some information on the character of strata of which cores are not obtained, and help to place recovered core sections in their correct stratigraphic position. In a few instances electrical logging has been used for the above mentioned purposes on a more or less experimental basis. More remote is the possibility that electrical logs may be used for determination of variations in water content of unsolidified deposits, and many correlations between such logs and the water contents of samples from the same borings will undoubtedly be required before reliable procedures of correlation and interpretation of the logs can be established. If such procedures could be developed, electrical logs may provide an economical means of estimating the maximum, minimum, and average values of the water content and, by further correlations, other significant physical factors or coefficients of entire deposits, whereas currently such average values are estimated on the basis of results of a relatively few laboratory tests.

Application of radioactivity logging in shallow borings is limited by the disturbing influence of surface conditions, but at greater depths the method may possibly be used for purposes similar to those of electrical logging. Neutron logs may give an indication of the relative water contents of similar strata, and gamma ray logs, taken before and after addition of a radioactive tracer to the wash water or drilling fluid, may help to establish both location and extent of subsurface fissures and cavities.

A periscope, consisting of brass tubing with a telescope at its upper end and a light source and a mirror at the lower end, has been used for examination of dry bore holes up to 75 ft deep, Lewis (949). A deep-well camera can be used at any depth in both dry and water-filled holes and may be very useful in obtaining details of cavities, fissures, and fault zones, especially after the location of such irregularities has been established by examination of cores or by use of any of the above mentioned logging methods.

A-7 Preparation of Test Specimens

A detailed description of methods for preparation of test specimens is outside the scope of this report, but a brief review is presented in the following paragraphs

in order to call attention to possible disturbances of the soil during cutting and trimming operations.

General.- Samples preserved in liners divided into very short sections, which form an integral part of the testing apparatus, are prepared for testing merely by cutting and trimming the sample at the joints between liner sections. When the sample is removed from the sampling tube or liner and the test specimen has the same diameter as the sample, the preparation likewise is reduced to cutting the sample into appropriate lengths and trimming the end surfaces. In these cases disturbance of the soil during preparation for testing is reduced to a minimum, but it must be borne in mind that the soil close to the cylindrical surface of the sample usually is partially disturbed during sampling, especially when the area ratio of the sampler is increased by use of relatively thick, sectionalized liners.

When the diameter of the test specimen is smaller than that of the sample, the specimen may be prepared (1) entirely by cutting, trimming, and use of guides or a miter box, (2) by progressive trimming in front of a tube or ring as in advance trimming used in surface sampling, Fig. 134, and (3) by punching similar to drive sampling. Method (1) is generally used for preparation of long cylindrical or prismatic test specimens for unconfined compression and triaxial tests, but method (2) may be preferable when the soil is nearly cohesionless, very brittle, or fractured, and method (3) may be used to advantage when a slight disturbance of the test specimen can be tolerated. When the test specimen is wide and short -- as for consolidation, direct shear, and torsion shear tests -- the preliminary trimming is generally performed by means of guides and a miter box and the final trimming by method (2) or (3). The preparation of soil test specimens should be performed in a moist room, especially when extensive trimming operations are required, otherwise exposure of the sample may cause a significant decrease in water content of the soil.

Equipment.- Preliminary trimming of samples of very hard and tough soils may be performed with a hacksaw, but knives or special cutting tools should be used for the final trimming and in general when the soil is stiff and brittle. Samples of relatively soft and plastic soils are trimmed with a wire saw. As described in a recent paper by **McRae (A-22)**, an air jet may be used when the soil has very little cohesion, and a revolving needle roller may be employed for removing small stones and foreign objects from the soil. The hacksaw should have fine teeth, the edge of the knives or special cutting tools should be smooth and sharp, and piano wires used in saws should not be too thick. Heavy wire is often used in preference to thin wire in order to avoid breaking the wire when obstructions or stiff strata are encountered, but obstructions should be bypassed, the trimming is often easier, and the disturbance is always smaller when a thin wire is used. It is suggested that the wire thickness should not exceed 0.010 in. when the wire saw is used for final trimming.

Cutting and trimming.- Cylindrical test specimens may be prepared by use of circular end-guides, but the sample is generally trimmed on a potters wheel or vertical lathe, **McRae (A-22)**. It is essential that the spindle of such a wheel or

lathe should rotate without significant play or eccentricity. The end surfaces of cylindrical test specimens and all surfaces of prismatic specimens are cut by use of guides or a miter box. When the soil is relatively soft and plastic and very uniform, plane surfaces may often be cut to final shape in a single operation by use of a wire saw. However, progressive trimming is generally preferable and is required when knives are used. Serious disturbance of the soil or irregularities in the final shape of the specimen may be caused by attempts to cut large slices or sections off the sample, especially when thick and dull knives or saws with heavy wires are used. Small stones, shells, pieces of wood, and other obstructions should be bypassed temporarily by cutting around the objects, which thereafter should be removed very carefully and the voids, when required, filled with soil. Revolving needle rollers, mentioned above, may be used to advantage when the obstructing objects are relatively small.

Advance trimming.- The comments on advance trimming as used in surface sampling, pages 161 and 380-381, apply also to use of the method in preparation of test specimens. It is emphasized that the trimming should be progressive and very carefully and accurately performed, especially when the cylinder or ring does not have a sharp and well tapered cutting edge. Serious disturbance of the soil may occur when the sample is not trimmed closely to the final diameter and considerable force is used to advance the cylinder or ring, but misleading test results may also be obtained if the entire cylindrical surface of the sample is not in full and firm contact with the ring. Small stones and other obstructing objects should be removed with extreme care and the voids filled with soil. Long cylindrical test specimens are generally prepared with excess length and are cut to final length in a miter box, whereas short and wide specimens are trimmed in and also remain in the ring when the latter forms an integral part of the testing apparatus.

Punching.- Preparation of test specimens by punching is quick and easy compared with progressive trimming, but punching should be used only when the soil is uniform in character and not too stiff or brittle. Long cylindrical test specimens may be obtained with a thin-wall open tube or a piston sampler, Fig. 316, and a metal ring or square frame with an integral or auxiliary cutting edge may be used to prepare short and wide test specimens. The walls of the sampler or ring should be very thin and the cutting edge well tapered and sharp, but even then some displacement of soil will take place and may cause a minor disturbance of the test specimen. Unless the sample is much larger than the test specimen, very soft and sticky soils may undergo large deformations and relatively brittle soils may crack during the punching operation. This cause of disturbance can to some extent be eliminated by providing lateral support of the sample. Because of displacement of soil by the sampler or ring, the lateral support should be elastic rather than rigid and may be obtained, for example, by placing the sample in an oversize container or ring and filling the remaining annular space with loose sand. Short and wide test specimens should preferably be tested in the ring used in punching or should remain therein until placed in the testing apparatus.

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NAME INDEX

The following index contains the names of persons, firms, organizations, and institutions mentioned in the foreword, text, and figures, but it is not a name index to the bibliography.

SUBJECT INDEX

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